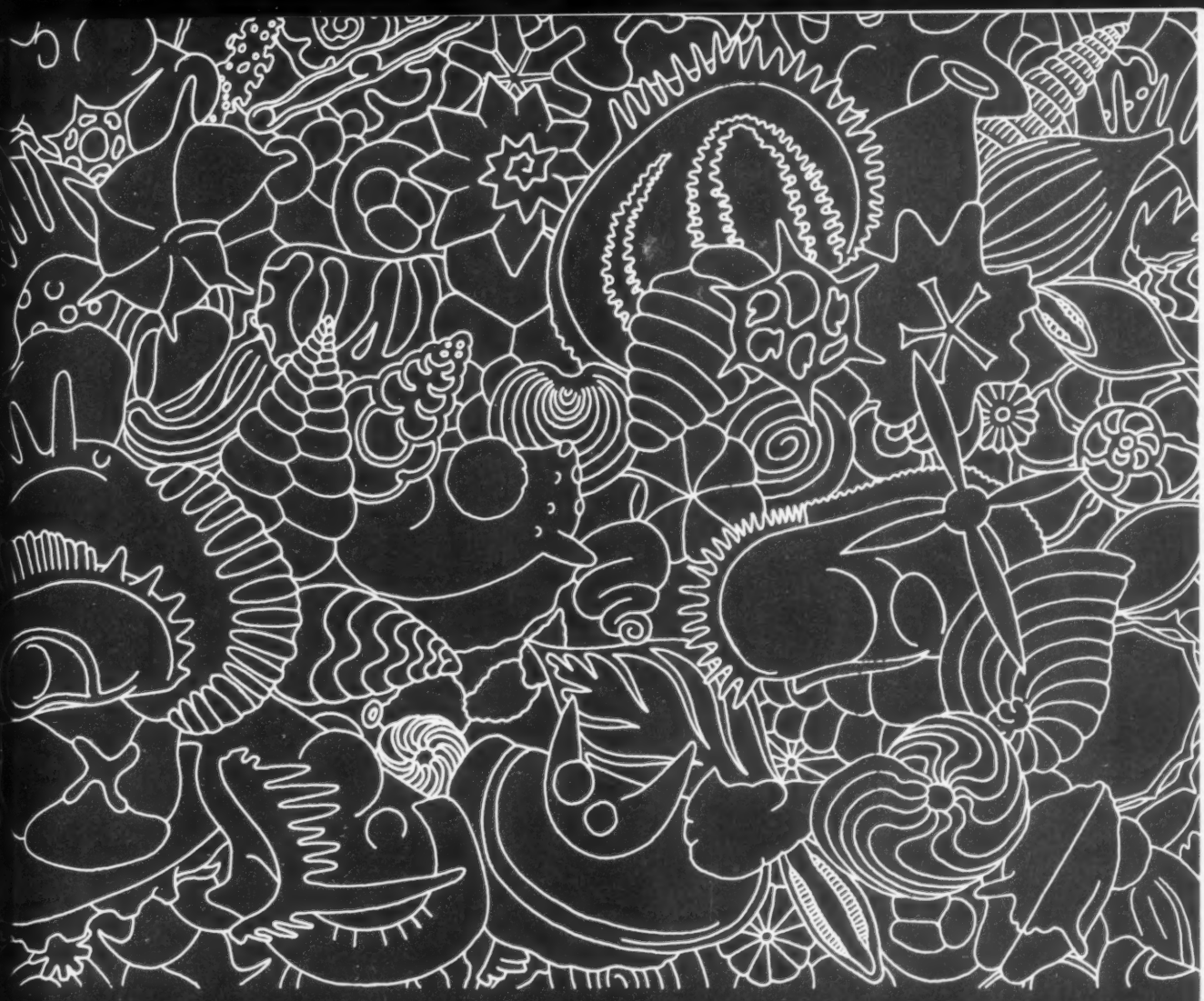

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ABSTRACT: *Some 48 species and subspecies of planktonic foraminifera, eight of which are new, have been identified and their stratigraphic ranges established in a closely sampled sequence of Miocene rocks from southeast Australia. Zoning based on the ranges of these foraminifera is discussed and the use of initial appearances of evolving species is strongly advocated. Intercontinental correlation of the foraminiferal zones is feasible and comparison with the Caribbean is reasonably close.*

Planktonic foraminifera from the Lakes Entrance oil shaft, Victoria, Australia

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INTRODUCTION

During the period 1941–1945, a vertical shaft having a diameter of 10 feet at the surface was put down into Tertiary rocks about a mile northeast of Lakes Entrance township, Victoria, in an attempt to tap an oil-bearing greensand (Boutakoff, 1951). Samples of the excavated rock were collected, only two being taken between 0–200 feet, but between 212 and 1204 feet samples were collected at intervals of four feet, under the personal supervision of Miss Irene Crespin of the Bureau of Mineral Resources, Canberra. During the year June, 1956 – June, 1957, the author, while working at this latter establishment, began an examination of these samples and this work was carried on and completed at the Department of Geology, Aberystwyth. The present paper discusses the taxonomy and biostratigraphy of the planktonic foraminifera found in these samples. The problems involved in long-range correlations are numerous, and some of these are discussed in the section following the systematic descriptions of the foraminifera.

PREVIOUS WORK IN THE AREA

A short summary report on the stratigraphy and general paleontology of the Lakes Entrance shaft has previously been given by Crespin (1947). An examination of the closely sampled rock sequence below 212 feet shows that it can be divided into three broad lithological units. The bottom 7 feet is composed of glauconitic greensand, overlain by 245 feet of micaceous marls and siltstones, which are sometimes glauconitic, above which there is 740 feet of bryozoal marls and limestones. There is no record of a stratigraphic or structural break in the sequence. The Tertiary of southeast Australia exhibits considerable facies variation and this has led to some disagreement as to its division into stratigraphic units. Glaessner (1951) divided the upper Eocene and middle Miocene rocks into three zones, the upper two zones being based on the ranges of benthonic foraminifera which are probably limited to fairly shallow water facies. Other Australian workers in this field questioned the validity of these zones and the postulated correlation with the European time scale (Crespin, 1952; Raggatt, 1952). More recently a considerable advance was made when Carter (1958*b*), working on the Aire District of Victoria, divided the Eocene-Miocene rocks into 11 numbered faunal units. Broadly speaking, Carter's faunal units 6–11 are equivalent to the shaft sequence from the pre-*Globoquadrina dehiscens dehiscens* zone up to and including part of the *Orbulina universa* zone. Accurate correlation of the individual units is difficult because there is some difference of opinion regarding the ranges of the planktonic foraminifera used to define some of the limits of Carter's faunal units (Jenkins, 1958).

THE ZONAL SUCCESSION

Where specific differences are only with difficulty or statistically definable, as in the case of organisms exhibiting wide phenotypic variation, and the ranges of the species are correspondingly vague, the zonal scheme is based on broadly defined assemblages of genera and species. This results in rather ill-defined and, usually, arbitrarily limited zones. Accurate delineation of paleontological zones can only be achieved by accepting either initial or final occurrences of one or more widespread species as marking the zonal boundaries. Examination of the ranges of the planktonic foraminifera in the Lakes Entrance shaft shows little simultaneity of appearances and extinction of the various species and consequently the zonal boundaries are defined with reference to single species or subspecies. As time markers, initial appearances of species or subspecies are preferred to final occurrences, because the first appearances are often relatively sudden events which are well marked by numerical 'bursts' of the incoming form, whereas extinctions tend to be gradual. Not all the initial appear-

TEXT-FIGURE 1

ances are held to have equal value as time markers, since species or subspecies evolving from widely distributed ancestral forms are more likely to appear simultaneously in various provinces than are species evolved from ancestors having restricted distributions. The eleven zones here proposed for the sequence in the Lakes Entrance shaft are therefore based on the initial appearances of forms whose origin usually is thought to be from widely distributed ancestral species. The base of each zone is defined by such an initial appearance and the name of the zone is taken from that species. The index fossil ranges throughout its zone and usually into the succeeding zone (or zones), the limits of which are, of course, defined by initial appearances of other forms. The sequence of zones, so defined, will now be described and the important initial occurrences and extinctions of species recorded within each zone (see text-figure 2 for sequence of zones and the ranges of the planktonic foraminifera).

PRE-GLOBOQUADRINA DEHISCENS DEHISCENS ZONE:
1204–1148 feet (text-figure 2, zone 1).

It is proposed to leave this zone so named until further work can be carried out on the planktonic foraminifera found in the sediments below the initial appearance of *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins) which defines the upper limit of this zone. The sample taken from 1204 feet yielded no planktonic foraminifera, but those from 1200 feet and 1196 feet yielded some 13 species and subspecies. This faunal increase is due to the facies change at this depth.

Initial appearances:
Globorotalia opima Bolli *continuosa* Blow, at 1156 feet.

Extinctions:
Globorotalia testarugosa, new species, at 1160 feet.

GLOBOQUADRINA DEHISCENS DEHISCENS ZONE:
1144–1000 feet (text-figure 2, zone 2).

The lower limit of this zone is defined by the initial appearance of *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins), and the upper limit by the initial appearance of *Globigerina woodi*, new species.

Initial appearances:
Globorotalia extans, new species, at 1136 feet.
Catapsydrax cf. *stainforthi* Bolli, Loeblich, and Tappan, at 1112 feet.
Globigerina ciperoensis ciperoensis Bolli, at 1096 feet.
Globigerina ciperoensis angustisuturalis Bolli, at 1020 feet.

Extinctions:
Catapsydrax unicavus Bolli, Loeblich, and Tappan, at 1092 feet.
Globigerina euapertura, new species, at 1092 feet.

GLOBIGERINA WOODI ZONE:
996–808 feet (text-figure 2, zone 3).

The lower limit of the zone is defined by the initial appearance of *Globigerina woodi*, new species, and its upper limit by the appearance of *Globigerinoides triloba triloba* (Reuss).

Initial appearance:
Globigerinoides triloba (Reuss) *altiapertura* Bolli, at 980 feet.

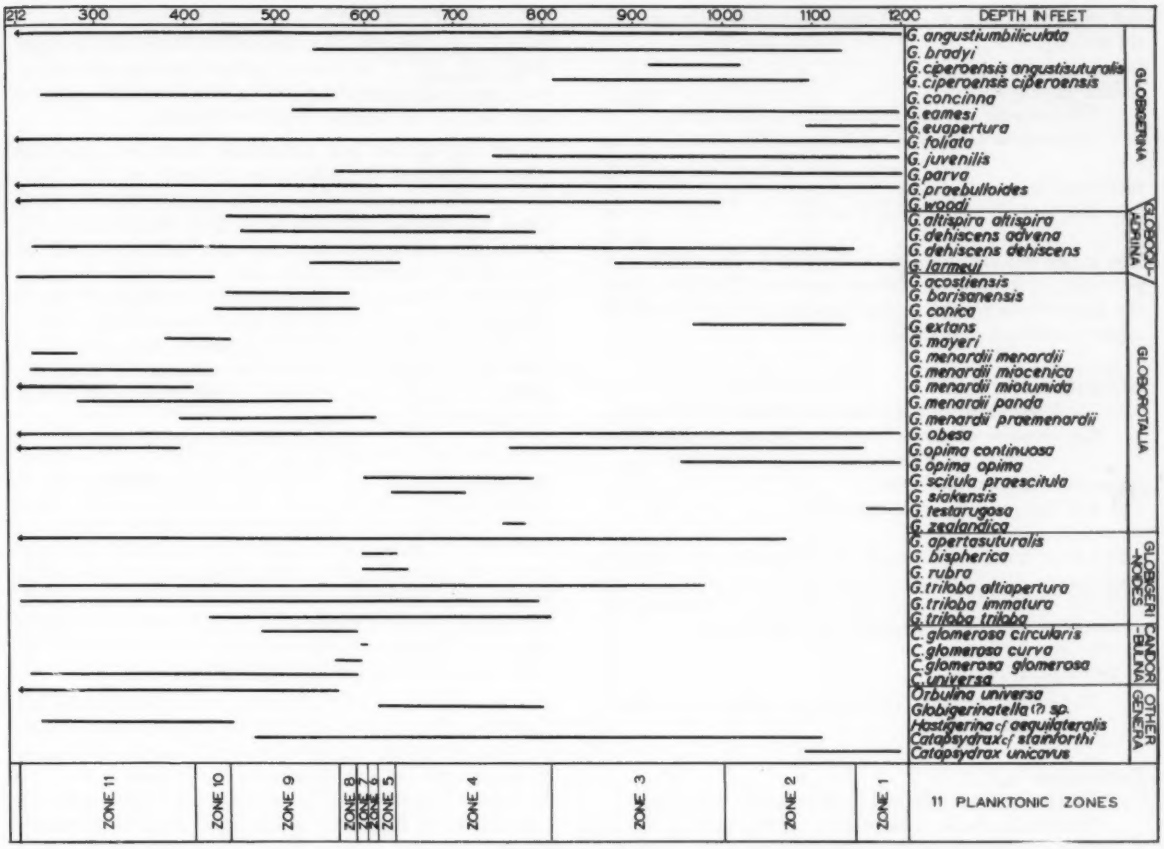
Extinctions:
Globorotalia opima opima Bolli, at 952 feet.
Globigerina ciperoensis angustisuturalis Bolli, at 916 feet.

GLOBIGERINOIDES TRILOBA TRILOBA ZONE:
804–632 feet (text-figure 2, zone 4).

The lower limit of this zone is defined by the initial appearance of *Globigerinoides triloba triloba* (Reuss) and its upper limit by the initial appearance of *Globigerinoides bispherica* Todd.

Initial appearances:
Globorotalia scitula praescitula Blow, at 788 feet.
Globoquadrina dehiscens (Chapman, Parr, and Collins) *advena* Bermudez, at 788 feet.
Globorotalia zealandica Hornibrook, at 776 feet.
Globoquadrina altispira altispira (Cushman and Jarvis) at 736 feet.
Globorotalia siakensis (LeRoy), at 712 feet.
Globigerinoides rubra (d'Orbigny), at 644 feet.

Extinctions:
Globorotalia opima Bolli *continuosa* Blow, at 760 feet.
Globorotalia zealandica Hornibrook, at 752 feet.
Globigerina ciperoensis ciperoensis Bolli, at 812 feet.



TEXT-FIGURE 2

Range chart of the planktonic foraminifera in the shaft sequence showing its division into 11 zones based upon the initial appearances of 10 species and subspecies.

GLOBIGERINOIDES BISPHERICA ZONE:
632–616 feet (text-figure 2, zone 5).

The lower limit of this zone is defined by the initial appearance of *Globigerinoides bispherica* Todd and the upper limit by the initial appearance of *Globorotalia menardii* (d'Orbigny) *praemenardii* Cushman and Stainforth.

Extinctions:
Globorotalia siakensis (LeRoy), at 628 feet.

GLOBOROTALIA MENARDII PRAEMENARDII ZONE:
612–604 feet (text-figure 2, zone 6).

The lower limit of this zone is defined by the initial appearance of *Globorotalia menardii* (d'Orbigny) *praemenardii* Cushman and Stainforth, and the upper limit by the initial appearance of *Candorbulina glomerosa curva* (Blow).

CANDORBULINA GLOMEROSA CURVA ZONE:
600–592 feet (text-figure 2, zone 7).

The lower limit of this zone is defined by the initial appearance of *Candorbulina glomerosa curva* (Blow) and the upper limit by the appearance of *Candorbulina glomerosa circularis* (Blow).

Initial appearances:
Globorotalia conica, new species, at 592 feet.

Extinctions:
Globigerinoides bispherica Todd, at 592 feet.
Globorotalia scitula praescitula Blow, at 596 feet.

CANDORBULINA GLOMEROSA CIRCULARIS ZONE:
588–572 feet (text-figure 2, zone 8).

The lower limit of this zone is determined by the initial appearance of *Candorbulina glomerosa circularis* (Blow) and

the upper limit by the appearance of *Orbulina universa* d'Orbigny.

Initial appearances:
Candorbulina universa Jedlitschka, at 588 feet.
Globorotalia barisanensis LeRoy, at 580 feet.

ORBULINA UNIVERSA ZONE:
568–452 feet (text-figure 2, zone 9).

The lower limit of this zone is defined by the initial appearance of the species *Orbulina universa* d'Orbigny and the upper limit by the initial appearance of *Globorotalia mayeri* Cushman and Ellisor.

Extinctions:
Candorbulina glomerosa glomerosa (Blow), at 564 feet.
Candorbulina glomerosa circularis (Blow), at 484 feet.

GLOBOROTALIA MAYERI ZONE:
448–412 feet (text-figure 2, zone 10).

The lower limit of this zone is defined by the initial appearance of *Globorotalia mayeri* Cushman and Ellisor and the upper limit by the appearance of *Globorotalia menardii* (d'Orbigny) *miotumida*, new subspecies.

Initial appearances:
Globorotalia menardii (d'Orbigny) *miocenica* Palmer, at 428 feet.

Extinctions:
Globigerinoides triloba triloba (Reuss), at 424 feet.
Globorotalia conica, new species, at 432 feet.
Globoquadrina altispira altispira (Cushman and Jarvis), at 444 feet.

GLOBOROTALIA MENARDII MIOTUMIDA ZONE:
408–212 feet (text-figure 2, zone 11).

The lower limit of the zone is taken where *Globorotalia menardii* (d'Orbigny) *miotumida*, new subspecies, makes its initial appearance and the upper limit at 212 feet (where the four foot sampling ends), although small specimens of this subspecies have been recovered from a sample taken between 170–200 feet.

Initial appearance:
Globorotalia opima Bolli *continuosa* Blow (making its second "initial appearance," which is discussed later in the systematic section) at 392 feet.

Extinctions:
Globorotalia menardii (d'Orbigny) *praemenardii* Cushman and Stainforth, at 392 feet.
Globorotalia menardii (d'Orbigny) *miocenica* Palmer, at 228 feet.
Candorbulina universa Jedlitschka, at 228 feet.
Globoquadrina dehiscens dehiscens (Chapman, Parr, and Collins), at 228 feet.

SYSTEMATIC DESCRIPTIONS

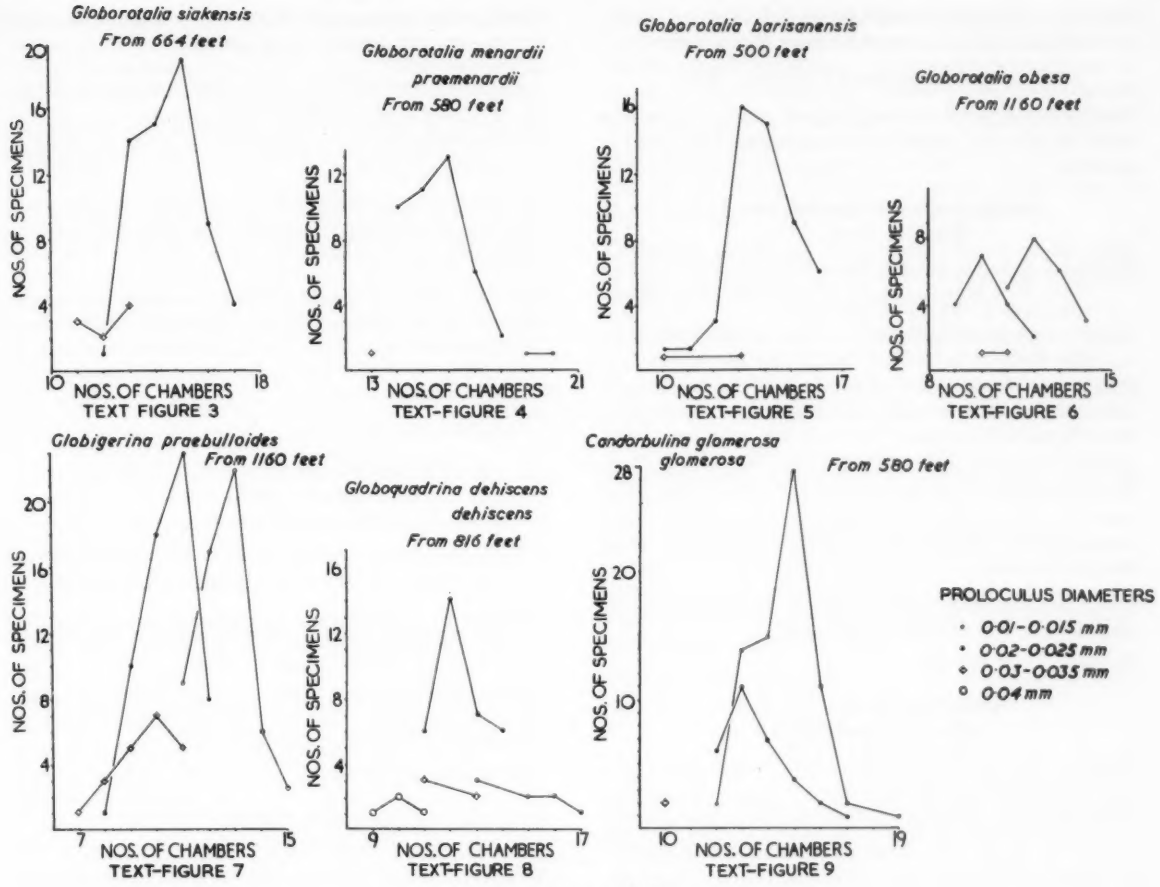
Morphology of the test: This subject has been dealt with by Bolli *et al.* (1957), but some further remarks are necessary, especially regarding the variation within a species and also on the subject of proloculus size.

In all the species and subspecies examined, the first whorl, excluding the proloculus, is made up of 5 chambers and this number seems to be fundamental. In most cases, the second chamber is slightly smaller than the proloculus. Thereafter there is a gradual increase in the size of the chambers. The size of the last chamber, especially in the genus *Globigerina* d'Orbigny and related genera, is seen to vary in size from larger to very much smaller than the penultimate chamber. When the final chamber is reduced to a flaplike structure (bulla) the specimens have been referred to the genus *Catapsydrax* Bolli, Loeblich, and Tappan.

The size and the shape of the aperture shows some variation. Within the genus *Globigerina* it can extend from the penultimate to the first chamber of the final whorl and then is slightly extraumbilical. When the last whorl is more tightly coiled the aperture becomes umbilical, extending from the penultimate to the antepenultimate chamber. These two apertural conditions are end-forms in a continuous growth series. Similarly the size of the last chamber also shows continuous variation in a sufficiently large population.

The size and shape of the umbilicus are linked with the tightness of coiling of the last whorl and the size and position of the last chamber. An examination was made of seven species and subspecies (text-figures 3–9) to determine the relationship between proloculus size and the number of chambers in the adult test. Within each group examined it was found that there is a direct relationship between the size of the proloculus and the number of chambers in the adult test. The tests with the small proloculus have the greater number of chambers, there being a decrease in the numbers of chambers with an increase in the diameter of the proloculus. Measurements were made of the proloculus diameters by converting the tests to fluorite (Grayson, 1956), smearing the initial part with glycerin and using an eyepiece micrometer. It was decided to divide the measurements into 4 groups: (1) 0.01–0.015 mm.; (2) 0.02–0.025 mm.; (3) 0.03–0.035 mm.; (4) 0.04 mm. and over. It is not possible to say whether the microspheric and megalospheric forms are represented; a study of living planktonic foraminifera will be necessary to decide this question. In the species and subspecies examined, it is not usually possible to distinguish by external size and morphology of the adult test those specimens having proloculi of notably different sizes, although in *Globigerina bradyi* Wiesner and *Globigerina eamesi* Blow the forms having smaller proloculi tend to have a more trochoid test.

Distinct adult forms, corresponding to markedly different proloculus sizes, are found only in *Globorotalia extans*, new species. In this species the forms with the smaller proloculi have five chambers in the final whorl as opposed



TEXT-FIGURES 3–9

Graphs illustrating the relationship between the proloculus diameters and the numbers of chambers in the adult tests of seven planktonic species and subspecies.

to four in the others. Occasionally forms occur which differ from allied species and subspecies only in having a final extra chamber, which is of a size and shape similar to the preceeding chamber. New taxa have sometimes been erected for the accommodation of such forms. Thus *Orbulina bilobata* (d'Orbigny) differs from *Orbulina universa* d'Orbigny only in having an extra final chamber, making it bilobed in appearance. Within any large population of *Orbulina universa* a small percentage is always found to have this extra chamber. Similar bilobed forms exist among the subspecies of *Candorbulina glomerosa* (Blow) and of *Globigerinoides triloba* (Reuss). Such forms having an extra final chamber are here regarded as end members of a growth series and are to be properly included in the taxa characterised by the normal chamber development.

In the following systematic descriptions of the species and subspecies the stratigraphic range refers to the shaft samples.

Family Hantkeninidae Cushman
Subfamily Hastigerininae Bolli, Loeblich, and Tappan
Genus Hastigerina Thomson, 1876

Hastigerina cf. **aequilateralis** (Brady)

Plate 1, figure 1a–c

Hastigerina cf. *aequilateralis* (Brady). – Bolli, 1957 (part), U.S. Nat. Mus., Bull. 215, p. 108, pl. 22, fig. 1a–c (not 2a–b).

Stratigraphic range: 452–236 feet; from the top of the *Orbulina universa* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This species is rare, found in only 3 samples, and these, like the specimens recorded by Bolli (1957*a*) from the Cipero formation, are more involute than Brady's types. *Globorotalia obesa* Bolli is a related form, but the aperture in this species never extends over the periphery onto the spiral side.

Hypotype: from 444 feet.

Family ORBULINIDAE Schultze
Subfamily GLOBIGERININAE Carpenter

Genus **Globigerina** d'Orbigny, 1826

Species belonging to this genus have globular chambers with an aperture which is interiomarginal-umbilical in position.

Globigerina angustiumbilicata Bolli
Plate 1, figure 2a–c

Globigerina ciperoensis angustiumbilicata BOLLI, 1957, U. S. Nat. Mus., Bull. 215, p. 109, pl. 22, figs. 12a–13c. – BOLLI, 1957, ibid. p. 164, pl. 36, fig. 6a–b.
Globigerina angustiumbilicata (Bolli). – BLOW, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 172, pl. 7, figs. 33a–c, 34.

Stratigraphic range: 1200 to 0–100 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This species is distinguished from *Globigerina ciperoensis ciperoensis* Bolli by having a smaller umbilicus and a lipped aperture. It seems to be related to *Globigerina parva* Bolli, but it has five chambers in the final whorl instead of four.

Globigerina angustiumbilicata occurs in 53 of the samples, and in these it is comparatively rare.

Hypotype: from 864 feet.

Globigerina bradyi Wiesner
Plate 1, figure 3a–b

Globigerina sp., BRADY, 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 603, pl. 82, figs. 8–9.
Globigerina bradyi WIESNER, 1931, Deutsche Südpolar-Exped. 1901–1903, vol. 20 (Zool., vol. 12), p. 133 (for figs., see BRADY, op. cit., fide ELLIS AND MESSINA, 1940 et seq.).—BOLLI, 1957, U. S. Nat. Mus., Bull 215, p. 110, pl. 23, fig. 5a–c.—BLOW, 1959, Bull. Amer. Pal., vol. 39, no. 178, pp. 173–174, pl. 7, fig. 36.

Stratigraphic range: 1132–548 feet; from the *Globoquadrina dehiscens dehiscens* zone to the *Orbulina universa* zone.

Remarks: This species occurs sporadically. It is found in only 12 of the samples and in these it is rare. The shaft specimens vary in length between 0.25–0.35 mm., which means that they are larger than those recorded by Brady (1884), Wiesner (1931), and Bolli (1957*a*). Forms with a proloculus diameter of 0.02 mm. have 13–14 chambers in the adult form, and those with a proloculus diameter of 0.01 mm. have 15–20 chambers. Specimens with small proloculi are usually more trochoid and compact, approaching the appearance of the holotype more closely. The less trochoid forms seem to be related to *Globigerina juvenilis* Bolli (Bolli 1957*a*, p. 111). The umbilicus is small, sometimes deep and in some forms the last chamber occupies the umbilical position, the aperture being small and slitlike. The chambers are usually ovate but in some of the more compact specimens, which are pyramidal in form, the chambers are elongate, parallel to the long axis of the test.

Hypotype: from 624 feet.

Globigerina ciperoensis Bolli subsp. **ciperoensis** Bolli
Plate 1, figure 5a–c

Globigerina ciperoensis BOLLI, 1954, Cushman Found. Foram. Res., Contr., vol. 5, pt. 1, p. 1.
Globigerina cf. *concinna* Reuss.—CUSHMAN AND STAINFORTH, 1945, Cushman Lab. Foram. Res., Spec. Publ. 14, p. 67, pl. 13, fig. 1a–b.

Stratigraphic range: 1096–812 feet; from the bottom of the *Globoquadrina dehiscens dehiscens* zone to the top of the *Globigerina woodi* zone.

Remarks: This subspecies is fairly common at the beginning of its range, with its maximum development between 1020 feet and 952 feet, but there is a definite fall-off in numbers towards the upper part of its range where it becomes rare.

Hypotype: from 1020 feet.

Globigerina ciperoensis Bolli subsp.
angustisuturalis Bolli
Plate 1 figure 4a–c,

Stratigraphic range: 1020–916 feet; from *Globoquadrina dehiscens dehiscens* zone to the *Globigerina woodi* zone.

Remarks: In a sufficiently large enough population of *Globigerina ciperoensis* Bolli between 1020–916 feet, specimens can be found which have deepened U-shaped sutures and these are referred to *Globigerina ciperoensis angustisuturalis* Bolli. The sides of the deepened sutures seem to have fewer pores than the rest of the test.

Hypotype: from 988 feet.

Globigerina concinna Reuss
Plate 1, figure 6a–c

Stratigraphic range: 564–240 feet; from the bottom of the *Orbulina universa* zone to the top of the *Globorotalia menardii miotumida* zone.

Remarks: This species has five chambers in the last whorl as opposed to four in *Globigerina praebulloides* Blow, to which it is no doubt related. Marks (1951), in a re-examination of the Miocene foraminifera of the Vienna Basin, from where *Globigerina concinna* was originally described by Reuss (1850), concludes that it does merit specific rank. Bolli (1954) discusses this species and suggests that it is possibly limited to the Miocene. It differs from *Globigerina ciperoensis* Bolli in being larger, and in the shaft the two species are separated in time; *Globigerina concinna* makes its initial appearance 176 feet above the last appearance of *Globigerina ciperoensis*. It is comparatively rare, occurring in only 23 samples, and in these only a few specimens were present in the planktonic population.

Hypotype: from 344 feet.

Globigerina eamesi Blow
Plate 1, figure 7a–c

Stratigraphic range: 1196–520 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Orbulina universa* zone.

Remarks: This species is quite common in the lower half of the shaft but becomes rarer toward the top. In the Pozon formation of Venezuela, Blow (1959) found this species in much younger rocks. Usually the wall is rough to spinose, but there are smooth-walled forms in the present sequence, all gradations existing between these two types.

The size and position of the last chamber is variable and consequently the aperture varies slightly in position. Usually it is slitlike and umbilical, but in some forms the aperture has become reduced to a small sutural opening at the base of the final chamber on the umbilical side. When two of these sutural apertures are formed the specimens are referred to *Globigerinoides apertasuturalis*, new species.

The majority of adult specimens at 1160 feet have a proloculus diameter of 0.02 mm. with 9–12 chambers.

There are two rarer groups, one having a proloculus diameter of 0.01 mm. with 13–16 chambers, and the other with a proloculus diameter of 0.25 mm. with only 9 chambers.

Hypotype: from 1048 feet.

Globigerina euapertura Jenkins, **new species**
Plate 1, figure 8a–c

Test trochospiral, compact, spiral side slightly convex, umbilical side convex, equatorial periphery quadrilobate, axial periphery rounded. Wall calcareous, perforate, surface coarsely pitted. Chambers of the final whorl slightly compressed, about 11–13 arranged in $2^1/_2$ whorls, usually $3^1/_2$ in the last whorl, increasing fairly rapidly in size. Sutures on the spiral side slightly recurved, depressed; on the umbilical side radial, deepened. Umbilicus fairly small, deep. Aperture distinct, fairly low arch with a rim, interiomarginal, umbilical. Largest diameter of holotype 0.30 mm.

Stratigraphic range: 1196–1092 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the middle of the *Globoquadrina dehiscens dehiscens* zone.

Remarks: Globigerina euapertura, new species, has a limited stratigraphic range and occurs in 23 samples out of the 27 within its range.

The height of the aperture is found to vary in most of the populations. In the young forms the aperture is usually a high arch resembling that of *Globigerina ampliapertura* Bolli, but it becomes a much lower arch as the chambers increase in size. In the more loosely coiled forms the last chamber becomes further removed from the umbilicus and the aperture becomes larger.

The last chamber varies in size from larger to smaller than the penultimate chambers, the smallest being in the form of a bulla over the umbilicus. When this is so, the forms are referred to *Catapsydrax unicavus* Bolli, Loeblich, and Tappan, whose range in the shaft is the same as *Globigerina euapertura*, new species.

There is a gradual increase in the size of the tests from 0.32 mm. at 1196 feet to 0.4 mm. at 1120 feet, this being due to a slight increase in the number of chambers. In the adult test the chamber number is decided by the size of the proloculus. The commonest forms are those with a proloculus diameter of 0.02 mm., with 12–13 chambers; the next most common have a 0.01 mm. proloculus, and 14–16 chambers, and the rarest forms have a 0.035 mm. proloculus and 10–11 chambers.

Globigerina euapertura, new species, seems to be intermediate in morphology between *Globigerina venezuelana* Hedberg and *Globigerina ampliapertura* Bolli.

It differs from *Globigerina venezuelana* in having a smaller test, being more loosely coiled, having a larger aperture and in not having a rounded subquadrate appearance peculiar to some of the *Globigerina venezuelana* specimens examined from the Cipero formation of Trinidad. *Globigerina euapertura*, new species, differs from *Globigerina ampliapertura* in having a lower arched aperture in the adult test.

It is possible that *Globigerina euapertura*, new species, is related to *Globigerina venezuelana* recorded by Bolli (1957*a*, p. 110) from the *Globigerina ampliapertura* zone of the Cipero formation of Trinidad (Dr. W. H. Blow, in a private communication).

Holotype: from 1188 feet.

Globigerina foliata Bolli
Plate 1, figure 9a–c

Stratigraphic range: 1196 to 0–100 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This is a comparatively rare species, occurring in only 25 samples. It is characterised by having discrete spherical chambers, with the sutures between them deeply incised. It is closely related to *Globigerina bulbosa* LeRoy, but this latter species has more elongate chambers.

Hypotype: from 1124 feet.

Globigerina juvenilis Bolli
Plate 1, figures 10a–c, 11a–c

Stratigraphic range: 1196–740 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to *Globigerinoides triloba triloba* zone.

Remarks: This species is fairly rare with a shorter range than that recorded by Bolli (1957*a*) and Blow (1959). Its morphology and its thin, very finely pitted wall make it distinctive. A related form occurs at 576, 548, and 452 feet, but it has a much larger test with a large umbilical aperture and a thicker lip. There is some variation in the position and shape of the last chamber; at 964 feet two specimens were found which have their last few chambers more drawn out and slightly pointed, with an umbilical aperture (Plate 1, fig. 11a–c).

The position of the aperture is also variable. The holotype has it on the ante-penultimate chamber, but in some forms it can open into the umbilicus, sometimes possessing a large thin lip.

Hypotypes: from 968 and 964 feet.

Globigerina parva Bolli
Plate 1, figure 12a–c

Stratigraphic range: 1200–568 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to bottom of the *Orbulina universa* zone.

Remarks: This is another rare species, occurring in only 7 samples. It is distinguished from *Globigerina angustiumbilicata* Bolli by having only 4 chambers in the final whorl instead of 5. In some samples there are intermediate forms, suggesting a close affinity between these two species.

Hypotype: from 1060 feet.

Globigerina praebulloides Blow
Plate 2, figure 1a–c

Globigerina praebulloides Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, pp. 180–181, pl. 8, fig. 47a–c, pl. 9, fig. 48.
Globigerina cf. *bulloides* d'Orbigny. — Cushman and Stainforth, 1945, Cushman Lab. Foram. Res., Spec. Publ. 14, p. 68, pl. 13, fig. 4a–b.
Globigerina aff. *bulloides* d'Orbigny. — Stainforth, 1948 (part), Jour. Pal., vol. 22, no. 2, p. 118, pl. 25, figs. 14–15 (not figs. 16–18).

Stratigraphic range: 1196 to 0–100 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to *Globorotalia menardii miotumida* zone.

Remarks: According to Blow (1959) an evolutionary series: *Globigerina praebulloides* Blow—*Globigerina parabulloides* Blow—*Globigerina bulloides* d'Orbigny can be recognised. Only the first species is recognised and comparison of the shaft specimens with Recent material containing *Globigerina bulloides* d'Orbigny support the view that they are different.

Hypotype: from 900 feet.

There is considerable variation within *Globigerina praebulloides* Blow, especially in the size of the final chamber, and this variation is continuous from forms where the last chamber is larger than the penultimate, to those in which it is much smaller. In the adult test the numbers of chambers present is dependent upon the size of the proloculus, and within a sufficiently large population there are three such sizes (text-figure 7).

Globigerina woodi Jenkins, **new species**
Plate 2, figure 2a–c

Globigerina cf. *trilocularis* d'Orbigny. — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 110, pl. 22, figs. 8a–9c.

Test a low trochospire, equatorial periphery trilobate to quadrilobate. Axial periphery rounded. Wall calcareous, perforate, usually coarsely pitted. Chambers 12–14 in number arranged in 2–3 whorls, spherical to ovate, appressed, with 3–4 chambers in the final whorl. Distinct radial sutures on both umbilical and spiral sides, depressed and tending to be U-shaped in the thicker walled tests. Umbilicus small. Aperture a medium-sized arch, interiomarginal, umbilical, with a clear, small fimbriate liplike margin around its border. Greatest diameter of holotype 0.45 mm.

Stratigraphic range: 996 to 0–100 feet; from the *Globigerina woodi* zone to the *Globorotalia menardii miotumida* zone.

Remarks: The size of the last chamber varies from much smaller to larger than the penultimate chamber. The position of the aperture varies from centrally placed to slightly extraumbilical, depending on the size and position of the last chamber. The size of the aperture also varies from a small low arch to a semicircular arch which resembles that of *Globigerina apertura* Cushman. Questioned specimens of the latter species occur sporadically in the upper part of the sequence. There are some species similar to *Globigerinoides triloba* (Reuss) *immatura* LeRoy, but they do not have any visible apertures. This species dominates the planktonic populations above 928 feet, its arched aperture, coarse wall, and compact form readily distinguishing it from the other species. It is ancestral to *Globigerinoides triloba* (Reuss).

Globigerina woodi has probably evolved from a variety of *Globigerina praebulloides* Blow, which tends to have only 3 chambers in the final whorl, and occurs abundantly in the bottom part of the shaft. These latter forms have a smoother test ornamentation and a low arched aperture. These are possibly *Globigerina* cf. *trilocularis* d'Orbigny of Bolli (1957b) from the Eocene Navet and San Fernando formations of Trinidad. This new species has been named after Professor Alan Wood, in recognition of his contributions to the study of foraminifera.

Holotype: from 900 feet.

Genus **Globigerinoides** Cushman, 1927

The genus *Globigerinoides* has evolved from *Globigerina* d'Orbigny by the development of supplementary sutural apertures on the spiral side of the test.

Globigerinoides apertasuturalis Jenkins, **new species**
Plate 2, figure 3a–c

Test a low trochospire with a trilobed equatorial periphery. Wall calcareous, perforate, surface finely to coarsely perforate. Chambers ovate, the last chamber nearly equal in size to the penultimate chamber. Sutures slightly depressed on the spiral and umbilical sides.

Umbilicus very shallow. Apertures sutural, two, rarely three, at the base of the last chamber opposite the two umbilical sutures of the ante-penultimate chamber. Greatest diameter of holotype 0.35 mm.

Stratigraphic range: 1072 to 170–200 feet; from the *Globoquadrina dehiscens dehiscens* zone to the *Globorotalia menardii miotumida* zone.

Remarks: Both smooth walled and coarsely ornamented forms are found within this species, which suggests that it may be polygenetic. The smooth walled form is possibly related to *Globigerina eamesi* Blow and is much rarer than the coarser walled form which is related to *Globigerina woodi* new species. The more coarsely ornamented form is regarded as being the more typical.

Holotype: from 816 feet.

Globigerinoides bispherica Todd
Plate 2, figure 4a–c

Globigerinoides bispherica Todd, 1954, in Todd, Cloud, Low and Schmidt, Amer. Jour. Sci., vol. 252, no. 11, p. 681, pl. 1, figs. 1a–c, 4. — Blow, 1956, Micropaleontology, vol. 2, no. 1, p. 62, text-fig. 1, nos. 4–8; text-fig. 2, nos. 10–11. — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 114, pl. 27, fig. 1a–b. — Carter, 1958 (part), Geol. Surv. Victoria, Bull. 55, pp. 53–54, pl. 7, figs. 73–74 (not 70–72). — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 189, pl. 11, fig. 64.

Stratigraphic range: 632–592 feet. *Globigerinoides bispherica* zone to the *Candorbulina glomerosa curva* zone.

Remarks: This species has evolved from *Globigerinoides triloba triloba* (Reuss) by an increase in the size of the final chamber which embraces 15–30 percent of the chambers of the earlier part of the test.

It has a very short range in the shaft, much shorter than that suggested by Carter (1958*b*). It is possible to confuse this species with the larger specimens of *Globigerinoides triloba* (Reuss) *immatura* LeRoy but the distinguishing features are the enveloping last chamber, and the increase of the supplementary apertures from 2 to 4, at the base of the final chamber.

In the sample which contains the first specimens of *Globigerinoides bispherica* Todd, there are also present low spiral forms of *Globigerinoides rubra* (d'Orbigny). The young forms of both species, prior to the addition of the final chamber, appear to have the same morphology. Carter (1958*a*, pl. 7, figs. 70–74) figures such a specimen, but it is the adult form which distinguishes them. In *Globigerinoides rubra* (d'Orbigny) the apertures are high arched, whereas the more enveloping last chamber of *Globigerinoides bispherica* Todd has reduced the apertures to slits.

Hypotype: from 608 feet.

Globigerinoides rubra (d'Orbigny)
Plate 2, figures 8a–c, 9a–c

Globigerina rubra d'Orbigny, 1839, in Ramon de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 82, pl. 4, figs. 12–14 (fide Ellis and Messina, 1940 et seq.).
Globigerinoides rubra (d'Orbigny). — Stainforth, 1948, Jour. Pal., vol. 22, p. 122, pl. 26, figs. 11–12. — Bolli, 1957, U. S. Nat. Mus., Bull. 215, pp. 113–114, pl. 25, figs. 12a–13b; text-fig. 21, no. 6a–b. — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, pp. 192–193, pl. 11, fig. 70, pl. 13, fig. 69a–b.

Stratigraphic range: 644–592 feet; from the *Globigerinoides triloba triloba* zone to the *Candorbulina glomerosa curva* zone.

Remarks: This is a comparatively rare species, occurring in only 7 samples, with rather doubtful specimens at 528, 500 and 308 feet. Within this species there are two forms; the most common has a proloculus diameter of 0.01 mm. and 15–18 chambers, the test being of high trochoid form. The other form, which only occurs in two samples, has a proloculus diameter of 0.02 mm. and 11–13 chambers, and has a low trochoid test; it is more compact than the first form and is probably *Globigerinoides subquadrata* Bronnimann. Both forms have apertures which are fairly symmetrically placed above the sutures.

The last chamber in the high spired forms varies in size and shape and some specimens resemble *Globigerinoides obliqua* Bolli.

Hypotypes: from 592 feet.

Globigerinoides triloba (Reuss) subsp. **triloba** (Reuss)
Plate 2, figure 5a–c

Globigerina triloba Reuss, 1850, K. Akad. Wiss. Wien, Math.-Naturw. Cl., Denkschr., vol. 1, p. 374, pl. 47, fig. 11a–d (fide Ellis and Messina, 1940 et seq.).
Globigerinoides triloba (Reuss). — Blow, 1956, Micropaleontology, vol. 2, no. 1, p. 62, text-fig. 1, nos. 1–3.
Globigerinoides tribola triloba (Reuss). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, pp. 112–113, pl. 25, figs. 2a–c, text-fig. 21, no. 1a–b. — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 187, pl. 11, fig. 60a–b.

Stratigraphic range: 804–424 feet; from *Globigerinoides triloba triloba* zone to the *Globorotalia mayeri* zone.

Remarks: This species is present in 43 of the samples, which means that it is much rarer than *Globigerinoides triloba immatura* LeRoy. *Globigerinoides triloba triloba* has evolved from the *Globigerina woodi* populations by a reduction in the size of the umbilical aperture and the formation of a slitlike supplementary aperture opposite it at the base of the final chamber. Correlated morphological changes include a gradual deepening of the sutures and an increase in the size of the last chamber, which tends to embrace a small part of the test. Some of these morphological characters continue in time, become accentuated, and give rise to other species.

Hypotype: from 600 feet.

Globigerinoides triloba (Reuss) subsp. **altiapertura** Bolli
Plate 2, figure 6a–c

Stratigraphic range: 980–212 feet; from the *Globigerina woodi* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This is a fairly common species as it occurs in 50 of the samples. It has evolved from *Globigerina woodi*, new species, by the development of supplementary apertures on the spiral side, and this is the only difference

between the two species. The most distinguishing feature of this species is its high arched umbilical aperture. A related form is *Globigerinoides sacculifera* (Brady) *irregularis* LeRoy, but the latter subspecies has a more irregular growth and the supplementary apertures seem to be larger.

Hypotype: from 348 feet.

Globigerinoides triloba (Reuss) var. **immatura** Le Roy
Plate 2, figure 7a–c

Globigerinoides sacculiferus (Brady) var. *immatura* LeRoy, 1939, Natuurk. Tijdschr. Nederl.-Indie, vol. 99, pt. 6, p. 263, pl. 3, figs. 19–21 (fide Ellis and Messina, 1940 et seq.).
Globigerinoides sacculifera (Brady). — Cushman and Stainforth, 1945, Cushman Lab. Foram. Res., Spec. Publ. 14, p. 68, pl. 13, fig. 3.
Globigerinoides triloba immatura LeRoy. — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 113, pl. 25, figs. 3a–4; text-fig. 21, no. 2a–b. — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 188, pl. 11, fig. 62a–b.

Stratigraphic range: 788–216 feet; from the bottom of the *Globigerinoides triloba triloba* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This is a fairly common species, occurring in 117 of the samples. It has evolved from *Globigerina woodi*, new species, by a gradual reduction of the umbilical aperture and by the development of a supplementary aperture on the spiral side of the test. Forms with the same morphology as this species occur below 788 feet in the *Globigerina woodi* population, but lack the supplementary aperture.

In *Globigerinoides triloba immatura* the final chamber is smaller than the rest of the test, whereas in *Globigerinoides triloba triloba* the final chamber is larger and tends to embrace more of the test.

Within the *Globigerinoides triloba immatura – Globigerinoides triloba triloba* populations there are large bilobed forms which have an extra chamber, and these resemble *Globigerinoides transitoria* Blow and *Orbulina bilobata* (d'Orbigny) in general morphology.

Hypotype: from 604 feet.

Genus Globigerinatella Cushman and Stainforth, 1945

Globigerinatella(?) sp.
Plate 2, figure 10a–c

Test fairly high trochospire, equatorial periphery lobate. Chambers ovate, 16–19 in number; first 14–16 chambers normally coiled, gradually increasing in size, the last closing the umbilicus; 3–4 sutural chambers, small, inflated, developed at the umbilical end of the test usually where 3 sutures meet. Wall calcareous, fairly coarsely perforate. Apertures are small openings, sutural, developed in association with the sutural chambers.

Diameter of typical specimen: 0.35 mm.; from 632 feet.

Stratigraphical range: 796–612 feet; from the *Globigerinoides triloba triloba* zone to the *Globorotalia menardii praemenardii* zone.

Remarks: This is a rare species found in only 7 samples. It is a development of *Globigerinoides apertasuturalis*, new species. The small added sutural chambers are placed where three sutures meet, thus covering the small sutural apertures. These sutural chambers are not flattened and the apertures are never areal as in *Globigerinatella insueta* Cushman and Stainforth.

It was decided to record this form because it shows some affinity to *Globigerinatella insueta* Cushman and Stainforth and because its range approximates that of this species in the Cipero formation (Bolli 1957*a*).

Genus **Globoquadrina** Finlay, 1947

The laterally compressed chambers which give the test a quadrate appearance and the umbilical teeth distinguish this genus from *Globigerina* d'Orbigny, and *Globorotalia* Cushman.

Globoquadrina dehiscens (Chapman, Parr, and Collins) subsp. **dehiscens** (Chapman, Parr, and Collins)
Plate 3, figure 3a–c

Globorotalia dehiscens Chapman, Parr, and Collins, 1934, Linn. Soc. London, Jour. Zool., vol. 38, no. 262, p. 569, pl. 11, fig. 36a–c.
Globorotalia quadraria Cushman and Ellisor, 1939, Cushman Lab. Foram. Res., Contr., vol. 15, pt. 1, pp. 11–12, pl. 2, fig. 5a–c.
Globoquadrina subdehiscens Finlay, 1947, New Zealand Jour. Sci. Technol., sec. B, vol. 28, no. 5, p. 291 (not figured) (fide Ellis and Messina, 1940 et seq.).
Globoquadrina dehiscens (Chapman, Parr and Collins). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 111, pl. 24, figs. 3a–4c. — Carter, 1958, Geol. Surv. Victoria, Bull. no. 55, p. 56, pl. 8, figs. 85–87.
Globoquadrina dehiscens dehiscens (Chapman, Parr and Collins). — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 182, pl. 8, fig. 49a–c.

Stratigraphic range: 1144–228 feet; from *Globoquadrina dehiscens dehiscens* zone to *Globorotalia menardii miotumida* zone.

Remarks: This species is common to most of the samples within its range, but becomes rarer above 348 feet. In actual numbers within the planktonic populations, it is comparatively rare and its peak frequency is between 852–816 feet.

Globorotalia quadraria Cushman and Ellisor is regarded as being synonymous with this species, as has been previously suggested by Grimsdale (1951) and Blow (1959). Topotype specimens of *Globoquadrina subdehiscens* Finlay from the New Zealand Miocene have been examined, and it is found to belong to this subspecies. Within a

sufficiently large population, forms can be found in which the last chamber is reduced in size and lies in the umbilicus, obscuring it.

In the typical specimen the apertural face is finely punctate and is distinct from the other parts of the test which are coarsely pitted. The earlier forms of this species and *Globoquadrina larmeui* Akers, from which it is thought to have evolved, do not possess this 'clear area.'

Examination of 53 specimens from a depth of 816 feet shows a definite relationship between proloculus size and the number of chambers in the adult test; the smaller the proloculus the greater the number of chambers in the adult test (see text-figure 8).

Hypotype: from 1144 feet.

Globoquadrina dehiscens (Chapman, Parr, and Collins) subsp. **advena** Bermudez
Plate 3, figure 4a–c

Globoquadrina quadraria (Cushman and Ellisor) var. *advena* Bermudez, 1949, Cushman Lab. Foram. Res., Spec. Publ., no. 25, p. 287, pl. 22, figs. 36–38.
Globoquadrina dehiscens (Chapman, Parr, and Collins) var. *advena* Bermudez. — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 182, pl. 8, fig. 50a–b.

Stratigraphic range: 788–460 feet; from *Globigerinoides triloba triloba* zone to the *Orbulina universa* zone.

Remarks: The subspecies is distinguished from *Globoquadrina dehiscens dehiscens* by having a more tightly coiled test which closes the umbilicus and obscures the finely pitted apertural face. It occurs sporadically and has been found in 17 samples.

Hypotype: from 696 feet.

Globoquadrina altispira (Cushman and Jarvis) subsp. **altispira** (Cushman and Jarvis)
Plate 3, figure 5a–c

Globigerina altispira Cushman and Jarvis, 1936, Cushman Lab. Foram. Res., Contr., vol. 12, pt. 1, p. 5, pl. 1, figs. 13a–c, 14.
Globoquadrina altispira altispira (Cushman and Jarvis). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 111, pl. 24, figs. 7a–8b. — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 183, fig. 51a–c.

Stratigraphic range: 736–444 feet, from *Globigerinoides triloba triloba* zone to *Globorotalia mayeri* zone.

Remarks: The specimens referred to this subspecies are rare, occurring in only 14 of the samples. It is distinguished from *Globoquadrina dehiscens dehiscens* by its more trochoid form and its relatively elongate, less compressed chambers. There are 4–5 chambers in the final whorl. The adult test has 15–17 chambers, with a proloculus diameter of 0.01–0.02 mm. This species probably evolved from *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins).

Hypotype: from 684 feet.

Globoquadrina larmeui Akers
Plate 3, figures 1a–c, 2a–c

Stratigraphic range: 1196–876 feet; 636–540 feet; total range from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Orbulina universa* zone.

Remarks: This species has two separate ranges in the shaft. In the first occurrence the species shows some morphological affinity to *Globigerina euapertura*, new species. The young forms of both species are alike. It seems likely that *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins) evolved from *Globoquadrina larmeui* by a further compression of the chambers with the concomitant development of the umbilical teeth. In the second occurrence of *Globoquadrina larmeui* Akers, which is well-separated from the first, the umbilical teeth are better developed in the larger specimens.

The holotype, figured by Akers (1955), has only 9 chambers and the proloculus has a diameter of approximately 0.04 mm., but the shaft specimens have 13–15 chambers with proloculus diameters of 0.01–0.02 mm.

Hypotypes: from 1036 and 636 feet.

Genus **Catapsydrax** Bolli, Loeblich, and Tappan, 1957

The genus *Catapsydrax* differs from *Globigerina* d'Orbigny in having a bulla covering the umbilicus, with associated infralaminal apertures (Bolli *et al.*, 1957, p. 36). If a specimen of the genus *Catapsydrax* is taken from a sample and the bulla removed by the application of dilute hydrochloric acid, the resulting *Globigerina* test is usually seen to have a proloculus size and chamber number which conform with a species of *Globigerina* from that sample. Hofker (1959) suggested that these forms are reproductive stages, and represent a sporulating condition. His main evidence for this is based upon the proloculus size which he claims to be smaller in the forms possessing bullae. We must, therefore, assume that Hofker's sporulating stage is equivalent to the microspheric form. It can be seen from Hofker's figures (1959, text-figs. 9–12) that *Globigerina venezuelana* Hedberg has 12 chambers, whereas *Globigerina venezuelana* forma *dissimilis* is shown to have only 9 normal chambers. From the study of the shaft specimens of *Globigerina* and related genera, it can be seen that the forms having smaller proloculi possess the greater number of chambers in the adult test. This is not in accordance with Hofker's theory. It should be noted that Hofker's figures of whole specimens do not show the initial parts clearly.

The holotype of *Catapsydrax dissimilis* (Cushman and Bermudez) is shown in the original figure to have a large proloculus with only 7 chambers composing the test. Within a large enough population of *Globigerina venezuelana* Hedberg from the Cipero marl, the last chamber varies from larger to much smaller than the penultimate chamber. In the forms with the small last chamber, its position is such that it tends to close the umbilicus. When

it lies over the umbilicus, then it is called a bulla and the specimen referred to *Catapsydrax dissimilis* (Cushman and Bermudez). Some specimens of *Globigerina venezuelana* from the Cipero marl have been converted to fluorite in order to examine the initial parts of the test. The proloculus size is seen to vary between 0.01–0.15 mm. with 18–19 chambers, and forms with bulla are seen to have a similar range of proloculus size, with 16–17 chambers in the adult test. At this stage of knowledge, it does not seem advisable to consider that the bulla have a definite morphological function without studying the present-day representatives of this group. It is possible that the sexual and asexual generations are not distinguished by proloculus size in this group.

Catapsydrax cf. **stainforthi** Bolli, Loeblich, and Tappan
Plate 3, figure 6a–c

Test weakly trochospiral, 10–11 chambers with 4 in the final whorl, ovate, appressed, increasing rapidly in size distally, producing a test that is more elongate axially than broad. Equatorial periphery quadrilobate, axial periphery rounded. Sutures on both umbilical and spiral sides flattened, depressed. Umbilicus covered by a small bulla, usually inflated, sometimes flattened. Apertures 3–4 sutural openings, with a small lip. Maximum diameter of holotype 0.27 mm.

Stratigraphic range: 1112–472 feet; from *Globoquadrina dehiscens dehiscens* zone to the *Orbulina universa* zone.

Remarks: The test, prior to the development of the bulla, is that of a *Globigerina praebulloides* Blow. The removal of the bulla by dilute hydrochloric acid and a critical examination of the test, including the proloculus diameter, confirms this. It is a rare form found in only 14 samples, and probably developed spontaneously at various times. The bulla varies from a bubble-shape to a flattened plate, but the apertures, 3–4 in number, are always sutural. The identification of this species is considered not quite certain because the holotype is shown to have 5 chambers in the final whorl, although in the description it is stated that four is the most common number. The shaft specimens have a longer range than those in the Cipero formation of Trinidad (Bolli 1957*a*).

Holotype: from 988 feet.

Catapsydrax unicavus Bolli, Loeblich, and Tappan
Plate 3, figure 7a–c

Stratigraphic range: 1196–1092 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Globoquadrina dehiscens dehiscens* zone.

Remarks: In a sufficiently large population of *Globigerina euapertura*, new species, there are forms in which the final chamber is greatly reduced. The bulla covers the umbilicus, and has a single opening. Such forms are referred to *Catapsydrax unicavus* Bolli, Loeblich, and Tappan.

Hypotype: from 1140 feet.

Subfamily ORBULININAE Schultze
Genus ORBULINA d'Orbigny, 1839

Orbulina universa d'Orbigny
Plate 3, figure 12

Orbulina universa D'ORBIGNY, 1839, in Roman de la Sagra, Hist. Phys. Pol. Nat. Cuba, Foraminifères, p. 2, pl. 1, fig. 1 (fide ELLIS AND MESSINA, 1940 et seq.).
Globigerina bilobata D'ORBIGNY, 1846, Foraminifères fossiles du bassin tertiare de Vienne, p. 164, pl. 9, figs. 11–14 (fide ELLIS AND MESSINA, 1940 et seq.).
Biorbulina bilobata (d'Orbigny). — BLOW, 1956, Micropaleontology, vol. 2, no. 1, p. 69, text-fig. 2, no. 16.
Orbulina universa d'Orbigny. — BOLLI, 1957, U. S. Nat. Mus., Bull. 215, pp. 115–116, pl. 27, fig. 5.

Stratigraphic range: 568 to 170–200 feet; from the *Orbulina universa* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This species differs from *Candorbulina universa* Jedlitschka by having no sutural apertures, all the pore-like apertures being scattered over the final chamber. Within most of the *Orbulina universa* populations in the shaft, there is a small percentage of adult tests that have an extra chamber or two, which vary in size from a mere pustule to a size as large as the preceding chamber. These forms have been given different specific names and were alloted generic status by Blow (1956). The author regards them as a growth form and therefore part of the species. Most of the specimens found in the shaft have been infilled with calcite and this makes it rather difficult to determine the initial parts, but individual adult specimens that have been converted to fluorite have yielded valuable information. The specimens examined have a proloculus diameter range of 0.01–0.02 mm. with 12–16 chambers, and the majority of these have the smaller diameter proloculus. According to Brady (1884, p. VIII), Schlumberger (1884) suggested that the large tests of *Orbulina universa* d'Orbigny which lack the small "*Globigerina* stage" are equivalent to the megalospheric condition in other species. Le Calvez (1936), working on Recent material, failed to identify the microspheric forms of this species, but he figures what is described as the megalospheric form which has a proloculus diameter of approximately 0.01 mm. If the microspheric proloculus is smaller than his, then it is exceptionally small.

Hypotype: from 380 feet.

Genus **Candorbulina** Jedlitschka, 1934

Remarks: The test is trochospiral, with the last chamber enveloping 40 per cent or more of the earlier part of the test, with four or more sutural apertures. Areal apertures may also be present on other parts of the test wall. It is distinguished from *Orbulina* d'Orbigny by having these sutural apertures.

Candorbulina glomerosa (Blow)

Globigerinoides glomerosa Blow, 1956, Micropaleontology, vol. 2, no. 1, pp. 64–65, text-fig. 1, nos. 9–19, text-fig. 2, nos. 1–4.
Globigerinoides transitoria Blow, 1956, ibid., pp. 65–66, text-fig. 2, nos. 12–15.
Porticulasphaera transitoria (Blow). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 115, pl. 27, fig. 3.

Stratigraphic range: 600–484 feet, from *Candorbulina glomerosa curva* zone to the *Globorotalia mayeri* zone.

Remarks: This species has been divided into three subspecies, and, for their detailed descriptions, see Blow (1956).

There are small specimens within this species that are distinctly trilobed and have small sutural apertures. These young forms, which have been called *Candeina triloba* Jedlitschka, and which are included by Bronnimann in his *Orbulina suturalis* (Bronnimann, 1951), have a sporadic occurrence in 23 of the samples between 580 and 292 feet.

At 580 feet, it was found that specimens of *Candorbulina glomerosa* (Blow) were not filled with calcite, and, on converting the specimens to fluorite, the initial parts were made visible. After a number of measurements had been made on 100 specimens it was found that (1) the smaller the proloculus the greater the number of chambers in the test, (2) there is a correlation between the length of the test prior to the addition of the final chamber and the diameter of the test, (3) there does not seem to be any correlation between the diameter of the proloculus and the diameter of the test.

Candorbulina glomerosa (Blow) subsp. **curva** (Blow)
Plate 3, figure 8

Globigerinoides glomerosa curva Blow, 1956, Micropalaeontology, vol. 2, no. 1, p. 64, text-fig. 1, nos. 9–14.
Porticulasphaera glomerosa curva (Blow). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 115, pl. 27, fig. 7.

Stratigraphic range: 600–592 feet; limited to the *Candorbulina glomerosa curva* zone.

Remarks: This subspecies has a very short range, occurring in only 3 of the samples. Bolli (1957*a*, fig. 18) shows it to occur before *Globigerinoides bispherica* Todd, but this is probably a printing error on the range chart.

Hypotype: from 592 feet.

Globorotalia glomerosa (Blow)
subsp. **glomerosa** (Blow)
Plate 3, figure 9a–b

Globigerinoides glomerosa glomerosa Blow, 1956, Micropaleontology, vol. 2, no. 1, p. 65, text-fig. 1, nos. 15–19; text-fig. 2, nos. 1–2.
Porticulasphaera glomerosa glomerosa (Blow). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 115, pl. 27, fig. 8.

Stratigraphic range: 592–564 feet; from the *Candorbulina glomerosa curva* zone to the *Orbulina universa* zone.

Remarks: This subspecies has quite a short range, and occurs in 7 of the samples. Specimens from 580 feet show that there is a relationship between proloculus diameter and the number of chambers in the adult test (see text-figure 9).

Hypotype: from 592 feet.

Candorbulina glomerosa (Blow) subsp. **circularis** Blow
Plate 3, figure 10a–b

Globigerinoides glomerosa circularis Blow, 1956, Micropaleontology, vol. 2, no. 1, p. 65, text-fig. 2, nos. 3–4.
Candorbulina universa Jedlitschka, 1934 (part), Naturf. Ver. Brunn, Verh., vol. 65 (1933), p. 24, text-figs. 4–6 (fide Ellis and Messina 1940, et seq.).
Orbulina suturalis Bronnimann, 1951 (part), Cushman Found. Foram. Res., Contr., vol. 2, pt. 4, p. 135, text-fig. 2, figs. 3–4, 9, 14.
Porticulasphaera glomerosa circularis (Blow). — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 115, pl. 27, fig. 2.

Stratigraphic range: 588–484 feet; from the *Candorbulina glomerosa circularis* zone to the *Orbulina universa zone.*

Remarks: This from has the longest range of the three subspecies, and occurs in 21 samples.

Hypotype: from 580 feet.

Candorbulina universa Jedlitschka
Plate 3, figure 11

Candorbulina universa Jedlitschka, 1934 (part), Naturf. Ver. Brunn., Verh., vol. 65 (1933), pp. 21, 24, text-figs. 1, 19 (fide Ellis and Messina, 1940, et seq.).
Orbulina suturalis Bronnimann, 1951 (part), Cushman Found. Foram. Res., Contr., vol. 2, pt. 4, p. 135, text-fig. 2, figs. 1, 2, 5, 6, 10; text-fig. 3, figs. 7, 11, 22; text-fig. 4, figs. 2, 3, 7, 11, 14, 15, 16, 19. — Blow, 1956, Micropaleontology, vol. 2, no. 1, p. 66, text-fig. 2, nos. 5–7. — Bolli, 1957, U. S. Nat. Mus., Bull. 215, p. 115, pl. 27, fig. 4.

Stratigraphic range: 588–228 feet; from the *Candorbulina glomerosa circularis* zone to the *Globorotalia menardii miotumida* zone.

Remarks: The last chamber envelopes 75 per cent or more of the earlier test, and the apertures are small porelike openings, present in the suture at the base of the final chamber and on this chamber (see Blow 1956). This species has evolved from *Candorbulina glomerosa circularis* (Blow) by a further enlargement of the final chamber and the spread of the apertures onto the surface of the final chamber.

Hypotype: from 572 feet.

Family Globorotaliidae Cushman

Genus **Globorotalia** Cushman, 1927

Hofker (1956) states that all the specimens of the genus *Globorotalia* have a poreless keel. The present author is inclined to follow other workers in including both

keeled and unkeeled forms within the genus, using other, seemingly more reliable morphological characters to determine the taxonomic position of the species and subspecies. These include the position of the aperture, which is umbilical-extraumbilical, and shape of the chambers, which are ovate to strongly compressed.

Globorotalia acostaensis Blow
Plate 4, figure 1a–c

Stratigraphic range: 432–212 feet, from *Globorotalia mayeri* zone to the *Globorotalia menardii miotumida* zone.

Remarks: Globorotalia acostaensis Blow has a low arched, lipped aperture, radial sutures and a thicker test, and these characters distinguish it from *Globorotalia mayeri* Cushman and Ellisor. Transitional forms between *Globorotalia barisanensis* LeRoy and *Globorotalia acostaensis* Blow occur between 452 and 420 feet. *Globorotalia acostaensis* is distinguished from *Globorotalia opima continuosa* Blow, which has 4 chambers in the final whorl, and a high arched aperture. These two species occur in close association in the samples, and are no doubt related.

Hypotype: from 224 feet.

Globorotalia barisanensis Le Roy
Plate 4, figure 2a–c

Globorotalia barisanensis LeRoy, 1939, Natuurk. Tijdschr. Nederl.-Indie, vol. 99, pt. 6, p. 265, pl. 1, figs. 8–10 (fide Ellis and Messina, 1940 et seq.).
Globorotalia fohsi barisanensis LeRoy. — Bolli, 1950, Cushman. Found. Foram. Res., Contr., vol. 1, pts. 3–4, p. 88, pl. 15, figs. 5, 6a–c. — Bolli, 1957 U. S. Nat. Mus., Bull. 215, p. 119, pl. 28, fig. 8a–c. — Blow, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 212, pl. 17, figs. 110, 111a–c.

Stratigraphic range: 580–444 feet, *Candorbulina glomerosa circularis* zone to *Globorotalia mayeri* zone.

Remarks: In the Cipero formation of Trinidad, Bolli (1950, 1957*a*) shows that this species evolves into a keeled form, and these have been further recorded by Akers (1955) and Blow (1959). In the shaft samples, there is no compression of the peripheral margin or a keel development in this species. Examination of specimens from the 500-foot level show that there is a definite relationship between proloculus diameter and the numbers of chambers in the adult test (see text-figure 5).

Hypotype: from 512 feet.

Globorotalia conica Jenkins, **new species**
Plate 4, figure 3a–c

Test umbilico-convex in shape, slightly longer than broad, equatorial periphery ovate, slightly lobate. Axial periphery subangular, rounded. Wall calcareous, finely perforate, smooth, except for minute pustules in front of the aperture on the umbilical surface of the first chamber of the final whorl. Chambers 13–16, proloculus diameter 0.02 mm., 5 angular-conical chambers in the last whorl. Spiral sutures stongly recurved, slightly depressed; umbilical sutures curved, slightly depressed. Umbilicus narrow, tending to be closed. Aperture a low arch with a slight lip, interiomarginal, extraumbilical-umbilical. Largest diameter of holotype 0.38 mm.

Stratigraphic range: 592–432 feet; *Candorbulina glomerosa curva* zone to the *Globorotalia mayeri* zone.

Remarks: This species is quite common in the samples and it is distinguished from *Globorotalia scitula praescitula* Blow by its conical shape. It differs from *Globorotalia*

EXPLANATION OF PLATES

PLATE 1

All figures × 60 unless otherwise noted.

1a–c *Hastigerina* cf. *aequilateralis* (Brady)
From 444 feet.

2a–c *Globigerina angustiumbilicata* Bolli
From 864 feet.

3a–b *Globigerina bradyi* Wiesner
From 624 feet.

4a–c *Globigerina ciperoensis angustisuturalis* Bolli
From 988 feet.

5a–c *Globigerina ciperoensis ciperoensis* Bolli
From 1020 feet.

6a–c *Globigerina concinna* Reuss
From 344 feet.

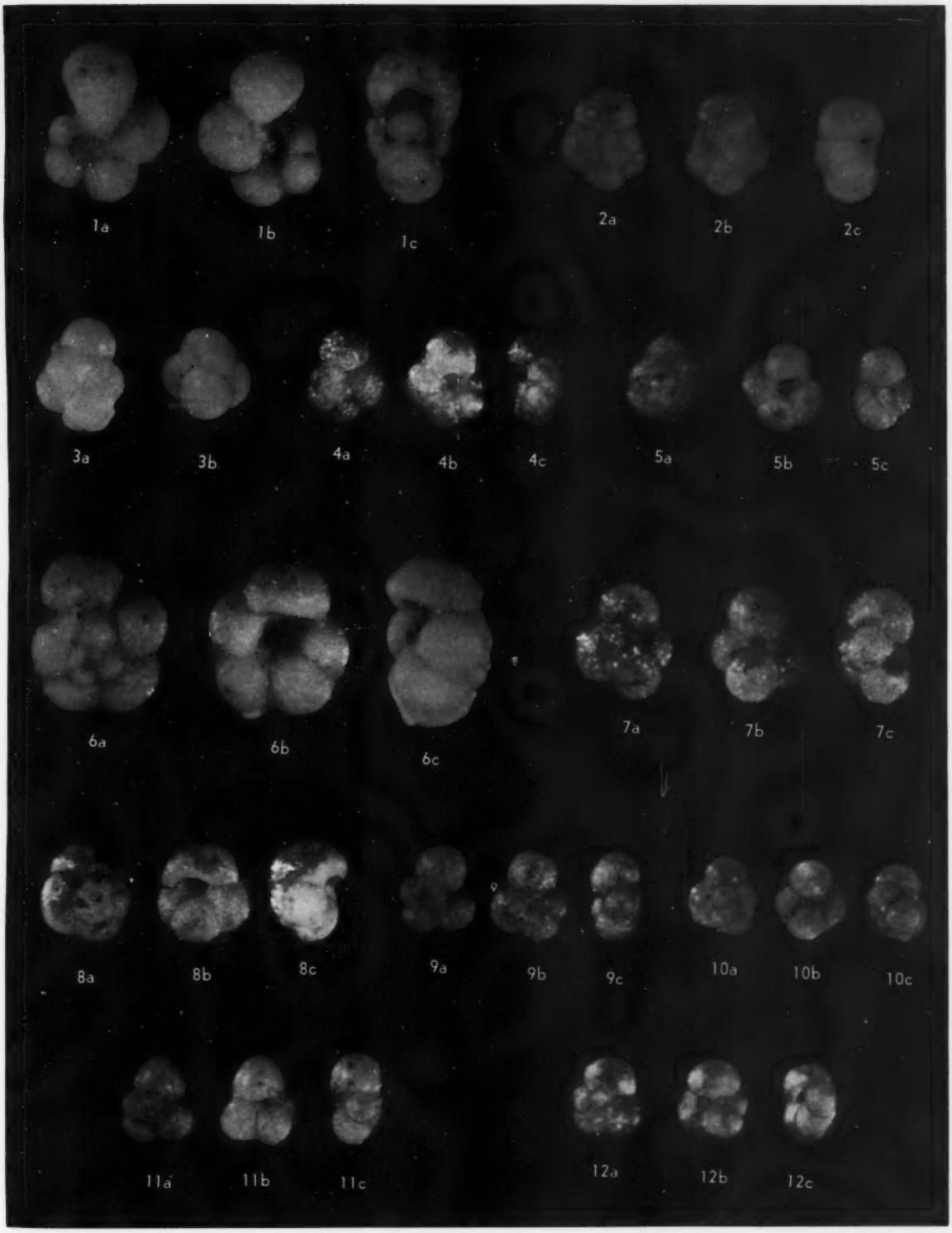
7a–c *Globigerina eamesi* Blow
From 1048 feet.

8a–c *Globigerina euapertura* Jenkins, n. sp.
From 1188 feet.

9a–c *Globigerina foliata* Bolli
From 1124 feet.

10a–c, 11a–c *Globigerina juvenilis* Bolli
From 968 feet and 964 feet, respectively.

12a–c *Globigerina parva* Bolli
From 1060 feet, × 100.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menardii d'Orbigny *miocenica* Palmer by not possessing a peripheral keel, and from *Globorotalia zealandica* Hornibrook by having a smoother wall, and more strongly recurved sutures on the spiral side, possessing the pustules in front of the aperture, and having 5 chambers in the final whorl.

Holotype: from 576 feet.

Globorotalia extans Jenkins, **new species**
Plate 4, figures 4a–c, 5a–c

Test a low trochospire, longer than broad, with a distinctly lobate equatorial periphery. Axial periphery rounded. Spiral side flattened, in some specimens slightly concave, umbilical side broadly convex. Wall calcareous, coarsely pitted. Microspheric forms with proloculus diameter of 0.01–0.15 mm., 13–15 chambers, with 5 in the final whorl, megalospheric forms with 0.02–0.03 mm. diameter proloculus, 10–11 chambers, with 4 in the final whorl. Sutures on both umbilical and radial sides depressed. Umbilicus narrow, deep. Aperture a low arch, slitlike, sometimes with a lip, interiomarginal, extraumbilical-umbilical. Largest diameter of holotype 0.35 mm. (microspheric) and of the paratype 0.29 mm. (megalospheric).

Stratigraphic range: 1136–964 feet, from the *Globoquadrina dehiscens dehiscens* zone to the *Globigerina woodi* zone.

Remarks: Between 1136–1080 feet, specimens of the microspheric and megalospheric forms exist together in the samples, but in the succeeding samples only the latter have been found. After its initial appearance there is a rapid increase in numbers, with a maximum at 1128 feet, then a gradual decrease as the species becomes rarer with the passage of time. Its distinctive features are its rather coarsely pitted wall, and the low arched aperture. This species differs from *Globorotalia testarugosa*, new species, by being more loosely coiled, and in having more inflated chambers, which results in a more lobate equatorial periphery. The aperture is much smaller than in *Globorotalia testarugosa*, and the megalospheric form is larger, with the sutures on the spiral side radial or slightly curved, and only 4 chambers in the final whorl.

Globorotalia extans, new species, is a distinctive species with a limited stratigraphic range. At its first occurrence, there is some evidence suggesting that this species has, by a reduction in the size of the aperture and its migration to an extraumbilical position, evolved from a *Globigerina* species with four chambers in the final whorl.

Holotype and paratype: from 1124 feet.

Globorotalia mayeri Cushman and Ellisor
Plate 4, figure 6a–c

Stratigraphic range: 448–376 feet: from the *Globorotalia mayeri* zone to *Globorotalia menardii miotumida* zone.

Remarks: Bolli (1957*a*) remarks that in the Cipero formation this species has a remarkably long range. In the shaft, its range is relatively short, and it is suggested that the early records of this species, prior to the appearance of *Orbulina universa* d'Orbigny, belong to *Globorotalia siakensis* (LeRoy). *Globorotalia mayeri* differs from *Globorotalia siakensis* in the following morphological features: (1) the aperture is always associated with a fairly large lip; it is a comparatively high arch which extends from the umbilicus to about halfway to the periphery producing, a "comma shape," whereas in *Globorotalia siakensis* the aperture is a low arch with a slight lip extending from the umbilicus to the periphery; (2) the chamber size increase is slower; (3) the spiral side is convex; (4) the test is never evolute; (5) the sutures are slightly curved, and this condition is shown in the holotype, whereas in *Globorotalia siakensis* the sutures are always radial.

Hypotype: from 444 feet.

Globorotalia menardii (d'Orbigny)

In the shaft samples five subspecies have been recognised, two of which are new.

PLATE 2

All figures × 60 unless otherwise noted.

1a–c *Globigerina praebulloides* Blow
From 900 feet.

2a–c *Globigerina woodi* Jenkins, n. sp.
From 900 feet.

3a–c *Globigerinoides apertasuturalis* Jenkins, n. sp.
From 816 feet.

4a–c *Globigerinoides bispherica* Todd
From 608 feet.

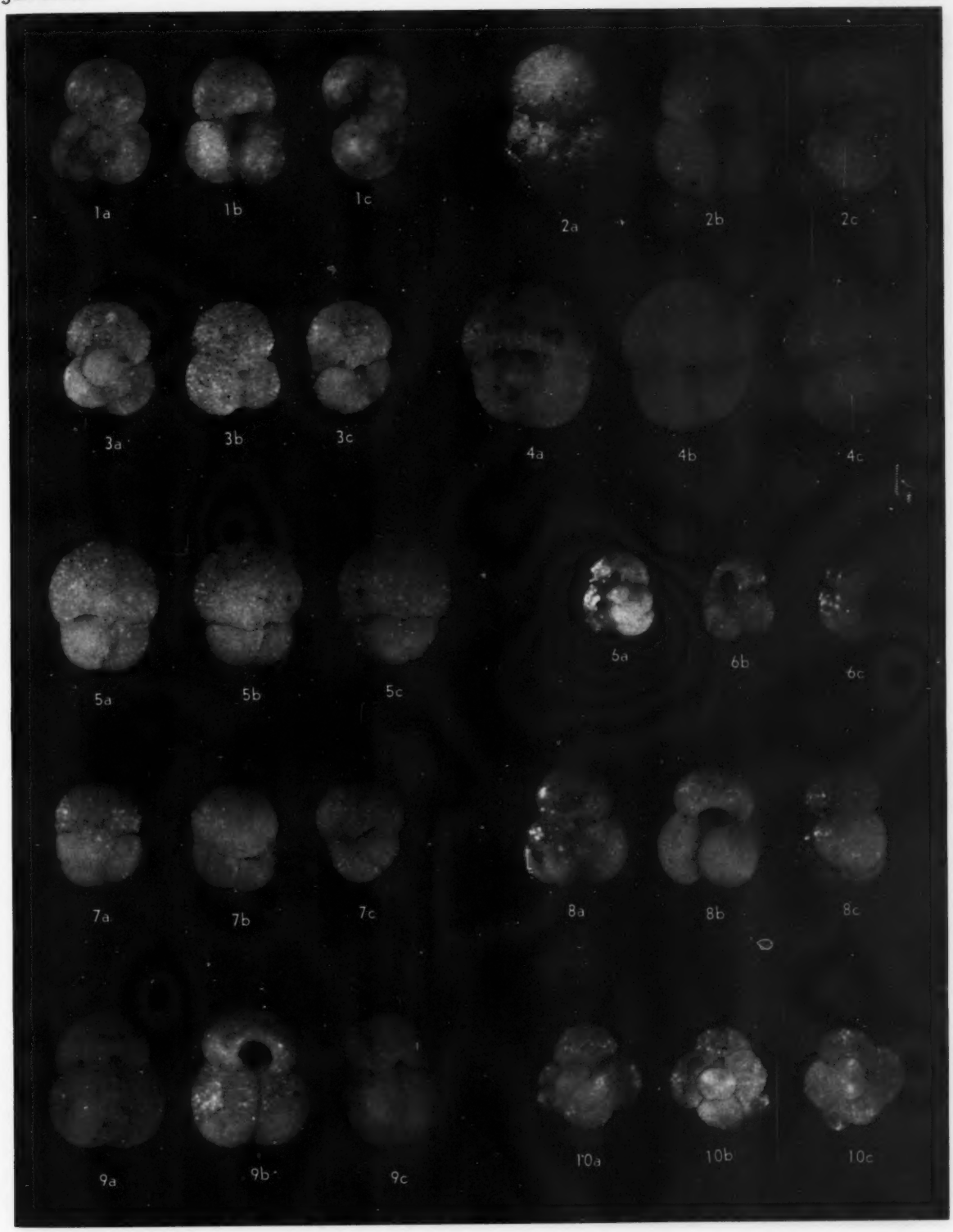
5a–c *Globigerinoides triloba triloba* (Reuss)
From 600 feet.

6a–c *Globigerinoides triloba altiapertura* Bolli
From 348 feet.

7a–c *Globigerinoides triloba immatura* LeRoy
From 604 feet.

8a–c, *Globigerinoides rubra* (d'Orbigny)
9a–c From 592 feet.

10a–c *Globigerinatella*(?) sp.
From 632 feet.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Globorotalia menardii (d'Orbigny)
subsp. **miocenica** Palmer
Plate 4, figure 7a–c

Stratigraphic range: 428–228 feet: limited to the *Globorotalia menardii miotumida* zone.

Remarks: Transitional forms between this subspecies and *Globorotalia menardii praemenardii* occur between 504 and 392 feet. These transitional forms have a slightly convex spiral side and a less vaulted umbilical side than *Globorotalia menardii miocenica*, which has a distinctive flat spiral side. After its initial appearance, *Globorotalia menardii miocenica* occurs sporadically in 12 samples.

Hypotype: from 428 feet.

Globorotalia menardii (d'Orbigny)
subsp. **menardii** (d'Orbigny)
Plate 4, figure 8–ac

Rotalia (Rotalie) menardii D'ORBIGNY, 1826, Ann. Sci. Nat., Paris, ser. 1., vol. 7, p. 273, Modèles no. 10 (fide ELLIS AND MESSINA, 1940, et seq.).
Globorotalia menardii (d'Orbigny) — BOLLI, 1957, U. S. Nat. Mus., Bull. 215, p. 120, pl. 29, figs. 6a–10b.

Stratigraphic range: 276–228 feet; this species is limited to the *Globorotalia menardii miotumida* zone.

Remarks: It differs from the other subspecies by having a flattened test, 5–6 chambers in the final whorl, and a lobate margin with a thickened keel. It has been found in only two samples in the upper part of the shaft; comparison with specimens from the Lengua formation of Trinidad, and with 'Challenger' specimens, confirms the identification. Bolli (1957*a*) states that there is considerable variation within this subspecies, but his illustrations (figs. 6a–10b) seem to represent a growth series.

Hypotype: from 276 feet.

Globorotalia menardii (d'Orbigny)
subsp. **miotumida** Jenkins, **new subspecies**
Plate 4, figure 9a–c

Test a low trochospire, the umbilical side slightly more convex. Equatorial periphery oval in outline, weakly lobate. Axial periphery acute, with a well-developed keel. Wall calcareous, finely perforate, smooth, except for small pustules developed in front of the aperture on the umbilical side. Chambers 13–15, with 4, rarely 5, in the final whorl, inflated umbilically. Sutures on the spiral side thickened, strongly recurved; umbilical sutures slightly curved, depressed. Umbilicus small. Aperture a low arch, interiomarginal, extraumbilical. Greatest diameter of holotype 0.40 mm.

Stratigraphic range: 408 to 170–200 feet; this species is limited to its own zone.

Remarks: Globorotalia menardii miotumida differs from the other subspecies by having a more compact test, with only 4 chambers in the final whorl. It is found in 21 of the samples but is rare, like all the planktonic foraminifera, in the upper part of the shaft.

Holotype: from 380 feet.

PLATE 3

All figures × 60 unless otherwise noted.

1a–c *Globoquadrina larmeui* Akers
2a–c From 1036 feet and 636 feet, respectively.

3a–c *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins)
From 1144 feet.

4a–c *Globoquadrina dehiscens advena* Bermudez
From 696 feet.

5a–c *Globoquadrina altispira altispira* (Cushman and Jarvis)
From 684 feet.

6a–c *Catapsydrax* cf. *stainforthi* Bolli, Loeblich and Tappan
From 988 feet.

7a–c *Catapsydrax unicavus* Bolli, Loeblich and Tappan
From 1140 feet.

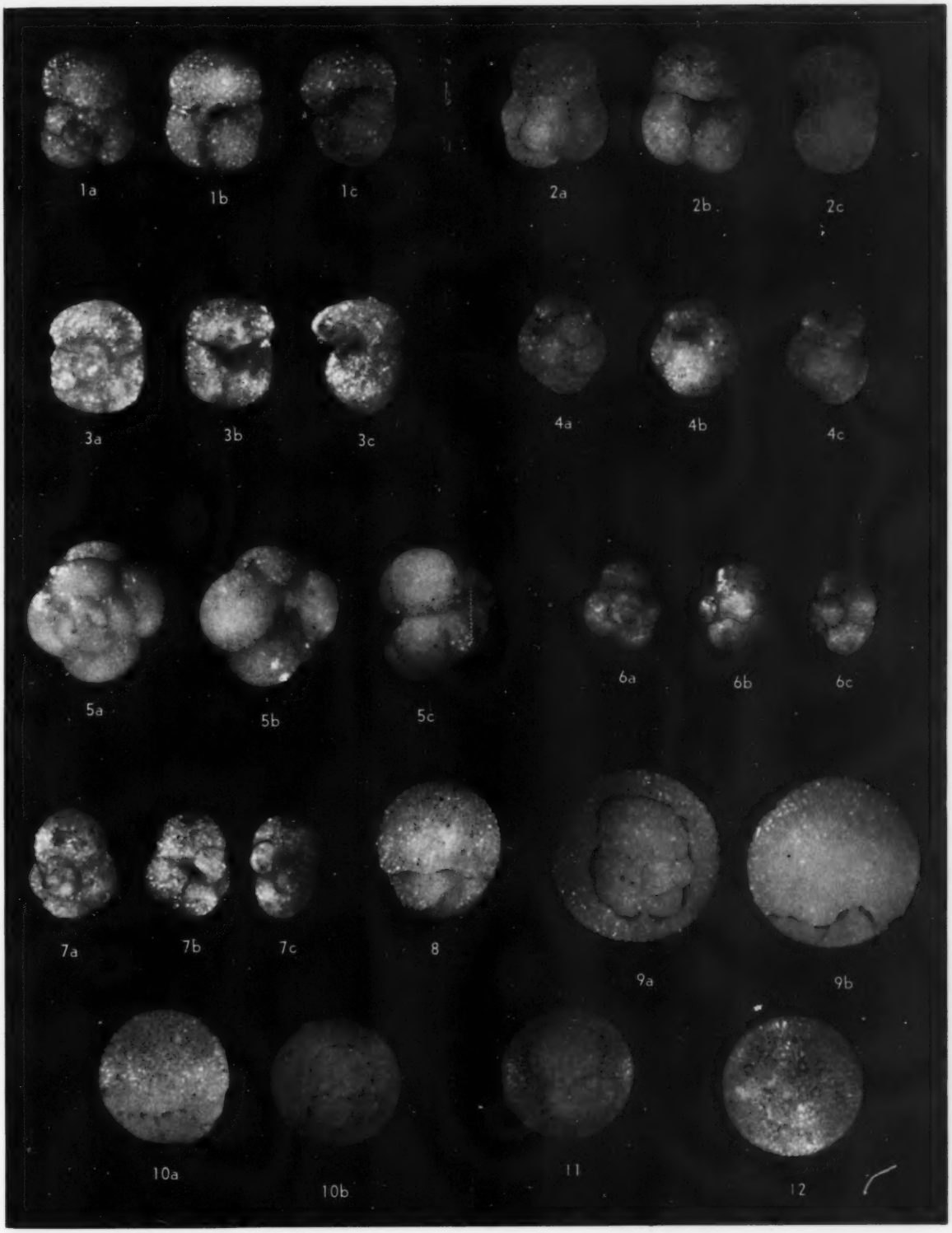
8 *Candorbulina glomerosa curva* (Blow)
From 592 feet.

9a–b *Candorbulina glomerosa glomerosa* (Blow)
From 592 feet.

10a–b *Candorbulina glomerosa circularis* (Blow)
From 580 feet.

11 *Candorbulina universa* Jedlitschka
From 572 feet.

12 *Orbulina universa* d'Orbigny
From 380 feet.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Globorotalia menardii (d'Orbigny)
subsp. **panda** Jenkins, **new subspecies**
Plate 4, figure 10a–c

Test spiroconvex. Equatorial periphery oval in outline. Very slightly lobate. Axial periphery acutely angular with a distinct, thick keel. Wall calcareous, finely perforate, smooth, with small pustules developed on the first chamber of the last whorl, in front of the aperture. Chambers 16–21, with 5 in the last whorl. Sutures on the spiral side limbate and strongly recurved, umbilical sutures radial, slightly thickened, depressed. Umbilicus small, closed in some specimens. Aperture a very low arch, lipped, interiomarginal, extraumbilical.
Largest diameter of holotype 0.62 mm.

Stratigraphic range: 560–276 feet; from the *Orbulina universa* zone to the *Globorotalia menardii miotumida* zone.

Remarks: Globorotalia menardii panda, new subspecies, is a rare form, found in only 6 of the samples. It differs from *Globorotalia menardii menardii* by having a more convex spiral side, the test being spiroconvex as opposed to a flattened biconvex form.

Holotype: from 408 feet.

Globorotalia menardii (d'Orbigny)
subsp. **praemenardii** Cushman and Stainforth
Plate 5, figure 1a–c

Globorotalia praemenardii CUSHMAN AND STAINFORTH, 1945, Cushman Lab. Foram. Res., Spec. Publ. 14, p. 70, pl. 13, fig. 14a–c. — BOLLI, 1957, U. S. Nat. Mus., Bull. 215, p. 120, pl. 29, fig. 4a–c.
Globorotalia archeomenardii BOLLI, 1957, ibid., pp. 119–120, pl. 28, fig. 11a–c.
Globorotalia menardii praemenardii Cushman and Stainforth. — BLOW, 1959, Bull. Amer. Pal., vol. 39, no. 178, p. 215, pl. 18, fig. 118a–c.

Stratigraphic range: 612–392 feet; from the *Globorotalia menardii praemenardii* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This subspecies has 5 chambers, rarely 6 in the final whorl, and the acute periphery has a narrow keel. At its initial appearance, only the last chamber possesses a keel, but in successive samples earlier chambers acquire it as the periphery becomes more acute. At 592 feet, all the chambers in the final whorl have a narrow keel, which tends to become stronger and better defined with time. In the upper part of its range, the test develops a more convex umbilical side, and these forms are transitional towards *Globorotalia menardii miocenica.*

The holotype of *Globorotalia archeomenardii* Bolli is small, having only 11 chambers, and compares well in size and morphology with 11-chambered forms of *Globorotalia menardii praemenardii.*

Examination of specimens from 580 feet show that adult tests with smaller proloculi have the greater number of chambers (see text-fig. 4).

Hypotype: from 608 feet.

Globorotalia obesa Bolli
Plate 5, figure 2a–c

Stratigraphic range: 1196–170–200 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Globorotalia menardii miotumida* zone.

Remarks: This species occurs very sporadically throughout the shaft section; such intermittent but persistent appearances and disappearances are rather difficult to explain. In general morphology it is nearer to the genus *Globigerina* d'Orbigny than any other *Globorotalia* in the samples. This fact is supported by the development of a bulla in some specimens from the lower part of the shaft. This structure is usually associated with certain species of *Globigerina.* There is a tendency for some specimens to become low trochoid to planispiral. Specimens examined at 1160 feet show that there is a relationship between the proloculus size and the number of chambers in the adult (see text-fig. 6).

Hypotype: from 1120 feet.

PLATE 4

All figures × 60 unless otherwise noted.

1a–c *Globorotalia acostaensis* Blow
From 224 feet.

2a–c *Globorotalia barisanensis* LeRoy
From 512 feet.

3a–c *Globorotalia conica* Jenkins, n. sp.
From 576 feet.

4a–c, 5a–c *Globorotalia extans Jenkins*, n. sp.
Figure 4 (megalospheric) and figure 5 (microspheric) from 1124 feet.

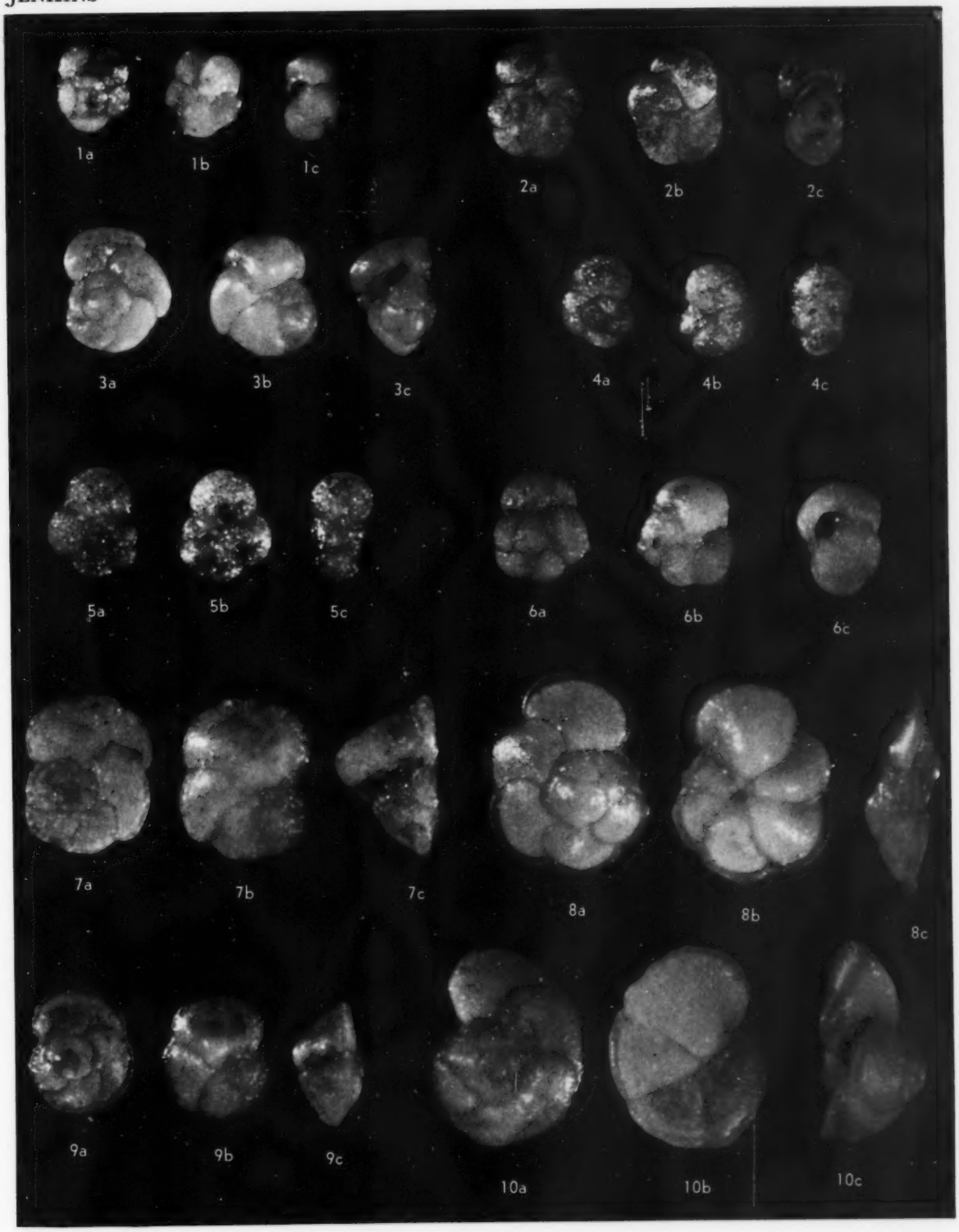
6a–c *Globorotalia mayeri* Cushman and Ellisor
From 444 feet.

7a–c *Globorotalia menardii miocenica* Palmer
From 428 feet.

8a–c *Globorotalia menardii menardii* (d'Orbigny)
From 276 feet.

9a–c *Globorotalia menardii miotumida* Jenkins, n. subsp.
From 380 feet.

10a–c *Globorotalia menardii panda* Jenkins, n. subsp.
From 408 feet.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10c

Globorotalia opima Bolli subsp. **opima** Bolli
Plate 5, figure 3a–c

Stratigraphic range: 1196–952 feet from the pre-*Globoquadrina dehiscens dehiscens* zone to *Globigerina woodi* zone.

Remarks: This subspecies is fairly common, occurring in 30 of the samples in a range of 244 feet. The shaft specimens are smaller than the holotype, the largest having a diameter of 0.42 mm. as opposed to the 0.55 mm. diameter of the holotype. It differs from *Globorotalia opima continuosa* Blow by having a smaller, lower arched aperture, and 5 chambers in the final whorl instead of 4. *Globorotalia opima nana* Bolli, from the Cipero formation of Trinidad, is a small form with 9–10 chambers, and from the description and figure of the holotype it appears to be a juvenile form.

Hypothype: from 1164 feet.

Globorotalia opima Bolli subsp. **continuosa** Blow
Plate 5, figures 4a–c, 5a–c

Stratigraphic range: 1156–760 feet; from the pre-*Globoquadrina dehiscens dehiscens* zone to the *Globigerinoides triloba triloba* zone; 392 to 0–100 feet: limited to the *Globorotalia menardii miotumida* zone.

Remarks: This subspecies was erected by Blow (1959) to include forms of the species having four chambers in the final whorl and a high arched lipped aperture. In the shaft such a form is seen to occur at two distinct levels. Specimens from its lower range in the shaft are a little larger than the holotype which is about the same size as the specimens from the upper part of its range. No distinction can be drawn between except that the aperture in the older forms is a little larger than that found in the specimens from the upper levels.

Hypotypes: from 816 and 348 feet.

Globorotalia scitula (Brady) subsp. **praescitula** Blow
Plate 5, figure 6a–c

Stratigraphic range: 788–596 feet; from *Globigerinoides triloba triloba* zone to *Candorbulina glomerosa curva* zone.

Remarks: The type specimens of *Globorotalia scitula scitula* (Brady) have been examined at the British Museum (Natural History), London, and it is seen that *Globorotalia scitula praescitula* differs from it in being about half its size, having a much thinner test wall, having a more convex umbilical side and a more acute periphery.

In the shaft samples *Globorotalia scitula praescitula* is a distinctive form and its initial appearance is sudden without suggestion of its ancestry. In the Pozon formation, Blow (1959) shows it giving rise to *Globorotalia scitula scitula*, but in the shaft there are no specimens of the latter subspecies in the samples.

Hypotype: from 684 feet.

Globorotalia siakensis (Le Roy)
Plate 5, figure 7a–c

Globigerina siakensis LeRoy, 1939, Natuurk. Tijdscher. Nederl.-Indie, vol. 99, pt. 6, p. 262, pl. 4, figs. 20–22 (fide Ellis and Messina, 1940 et seq.).

Stratigraphic range: 712–628 feet; from the *Globigerinoides triloba triloba* zone to the *Globigerinoides bispherica* zone.

Remarks: This species differs from *Globorotalia mayeri* Cushman and Ellisor in the following morphological features: (1) The aperture of *Globorotalia siakensis* is narrower and extends from the periphery into the umbilicus; (2) the chambers increase in size more rapidly in the final whorl which results in a more elongate test; (3) the spiral side is flatter, and (4) the test is usually somewhat evolute.

PLATE 5

All figures × 60 unless otherwise noted.

1a–c *Globorotalia menardii praemenardii* Cushman and Stainforth
From 608 feet.

2a–c *Globorotalia obesa* Bolli
From 1120 feet.

3a–c *Globorotalia opima opima* Bolli
From 1164 feet.

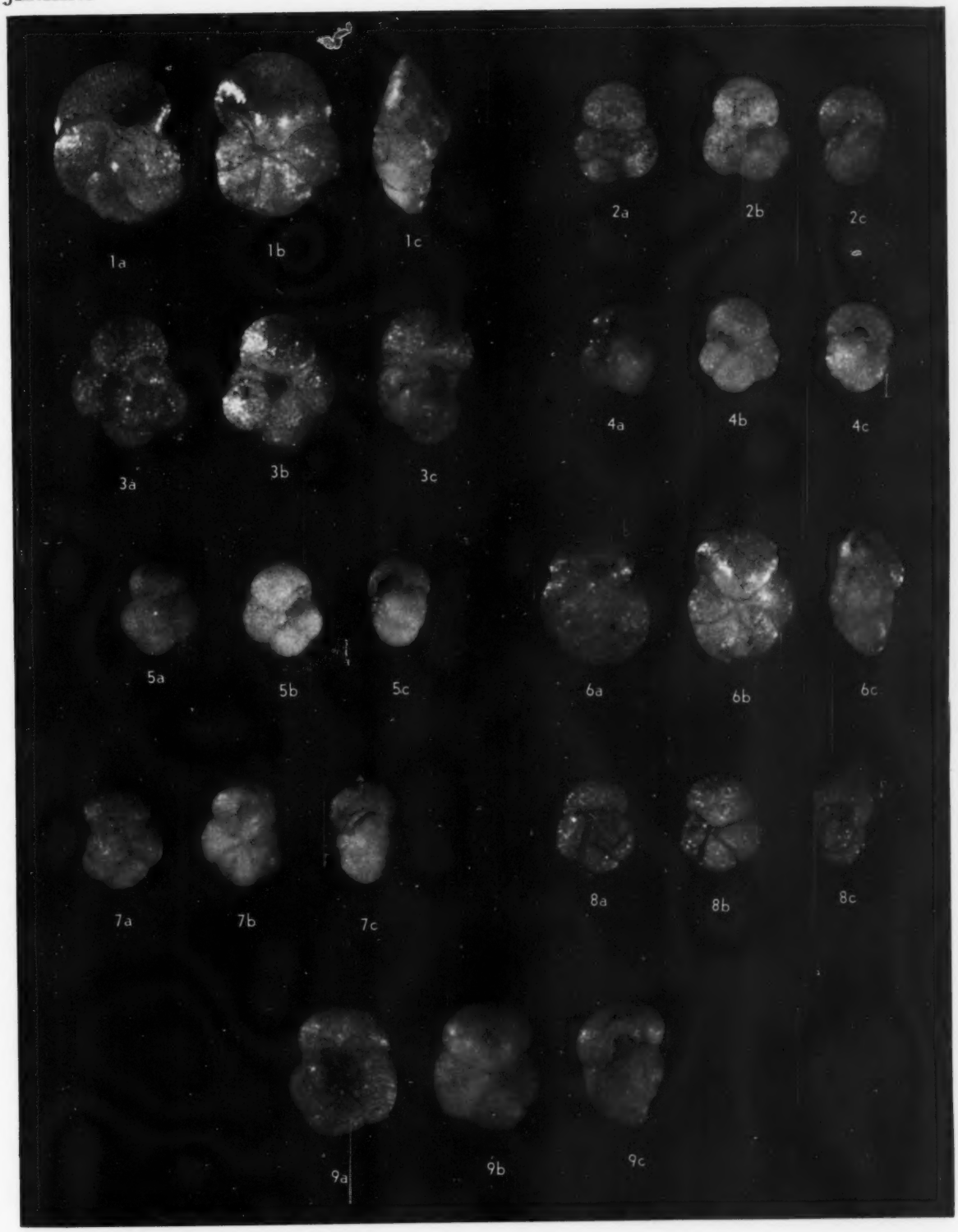
4a–c *Globorotalia opima continuosa* Blow
5a–c From 816 and 348 feet, respectively.

6a–c *Globorotalia scitula praescitula* Blow
From 684 feet.

7a–c *Globorotalia siakensis* (LeRoy)
From 684 feet.

8a–c *Globorotalia testarugosa* Jenkins, n. sp.
From 1192 feet.

9a–c *Globorotalia zealandica* Hornibrook
From 776 feet.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Direct comparison has made between the shaft specimens and topotype specimens of *Globorotalia siakensis* (LeRoy) kindly sent by Dr. L. Boomgaart from Sumatra. It has been found that they are closely similar, but there is a tendency for the *Globorotalia siakensis* population from Sumatra to have individuals with 6 chambers in the final whorl, whereas in the shaft only the 5-chambered forms are usually encountered.

Bolli (1957*a*) remarks that *Globorotalia mayeri* has a remarkably long range in the Cipero formation. It is suggested that the records of *Globorotalia mayeri* from rocks of pre-*Orbulina universa* age probably belong to the species *Globorotalia siakensis* LeRoy. In the shaft it is found that *Globorotalia mayeri* evolved from *Globorotalia barisanensis*. The range of this species in the shaft is limited; it is present in only 17 of the samples. The aperture is slitlike and narrow in the earlier forms but it becomes a little larger with time. Specimens from 664 feet show a definite relationship between proloculus diameter and number of chambers in the adult test (see text-fig. 3).

Hypotype: from 648 feet.

Globorotalia testarugosa Jenkins, **new species**
Plate 5, figure 8a–c

Test is a low trochospiral, equatorial periphery very slightly quadrilobate. Axial periphery rounded. Wall calcareous, coarsely perforate. Chambers inflated, flattened on the spiral side, numbering 11, with $4^1/_2$ in the final whorl increasing rapidly in size. Sutures on the umbilical side depressed and grooved, slightly curved; sutures on the spiral side straight, tangential, only slightly depressed. Umbilicus shallow. Aperture a low arch, interiomarginal, extraumbilical-umbilical, with a narrow lip. Greatest diameter of holotype 0.30 mm.

Stratigraphic range: 1200–1160 feet; this species is limited to the pre-*Globoquadrina dehiscens dehiscens* zone.

Remarks: This is a very rare species occurring in only 5 of the samples. The few specimens available for examination show two proloculus sizes: 0.03 mm. with 10–11 chambers, and 0.02 mm. with 13 chambers. The diagnostic features of this species are its coarsely pitted wall and the straight sutures on the spiral side of the specimens with the larger proloculus. This distinctive species has a very short range but its scarcity in the shaft samples diminishes its stratigraphic usefulness.

Holotype: from 1192 feet.

Globorotalia zealandica Hornibrook
Plate 5, figure 9a–c

Stratigraphic range: 776–752 feet; limited to the *Globigerinoides triloba triloba* zone.

Remarks: This is a fairly rare but distinctive species with a short range occurring in 7 consecutive samples. Hornibrook (1958) described *Globorotalia zealandica* from the Tertiary rocks of New Zealand where its range is given as Awamoan to Altonian. In terms of initial appearances of other planktonic foraminifera, given by Hornibrook (1957, table 1) this means that it ranges from the *Globigerinoides triloba triloba* zone to the *Globigerinoides bispherica* zone. Therefore in New Zealand it seems that this species has a longer range than in the shaft samples.

Globorotalia zealandica is distinguished from *Globorotalia conica*, new species, by having a smaller test, with 4, rarely 5 chambers in the final whorl, having a more coarsely pitted wall, not possessing pustules in front of the aperture on the umbilical surface and by having less strongly recurved sutures on the spiral side.

Hypotype: from 776 feet.

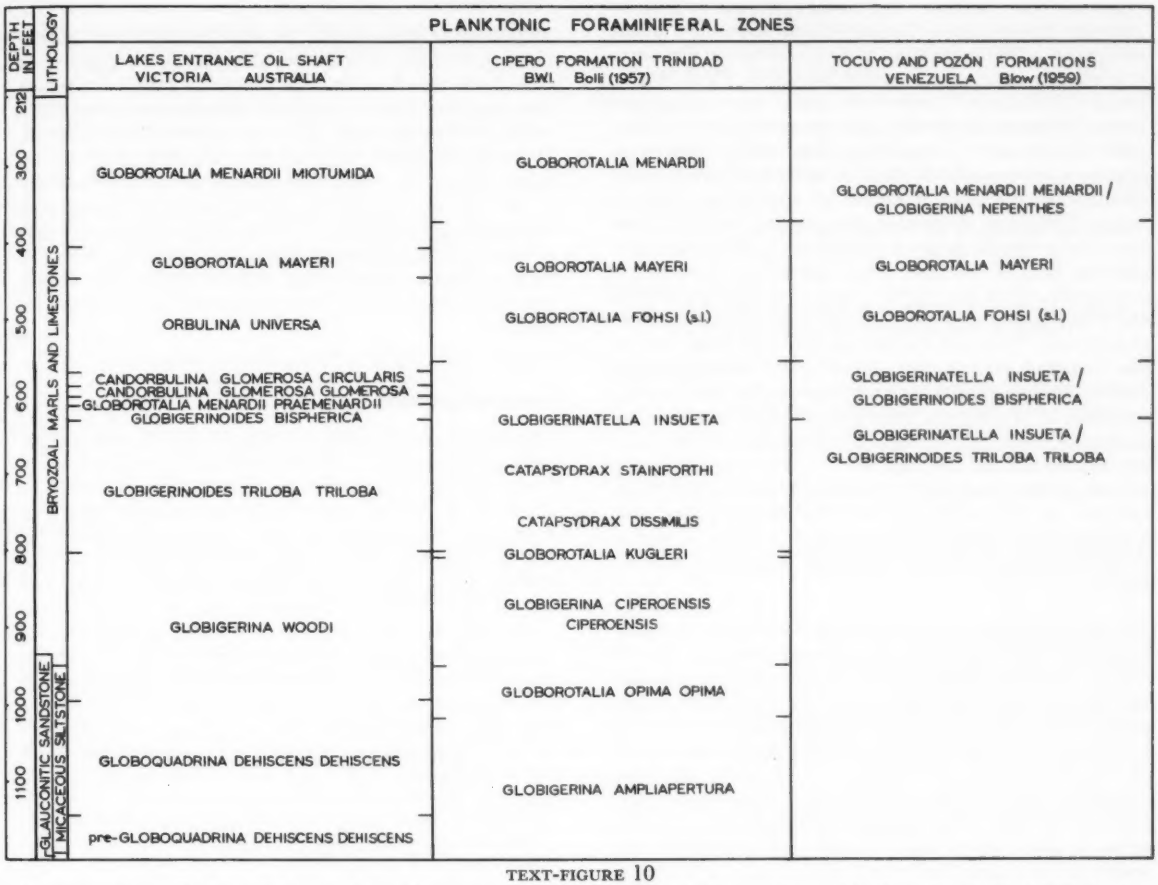
INTERCONTINENTAL CORRELATIONS

The smallest stratigraphic unit used in such a correlation is the zone, but since little work has been done on the zoning of the Middle Tertiary type areas in Europe using the ranges of planktonic foraminifera (see Drooger, 1956, for the difficulties involved), an attempt must be made to correlate the zones which have been established outside this region with only incidental, inexact reference to the type areas. Using planktonic foraminifera, Bolli (1957*a*) has divided the Cipero formation of Trinidad into 13 zones and Blow (1959), working on a Venezuelan sequence, was able to correlate his zones with those established by Bolli. This direct correlation was made possible by the similarity of the planktonic foraminiferal populations. Due probably to a latitude and depth difference, the planktonic foraminiferal populations of the Lakes Entrance Shaft, Victoria, are distinct in a number of respects from those described by Bolli and Blow from the Caribbean Tertiary. An instance of such a difference is the absence or rarity in the shaft of warm-water species as *Globigerinoides sacculifera* (Brady) and *Globigerinoides rubra* (d'Orbigny), which are common in the Caribbean sequences. On the other hand *Globigerina woodi*, new species, the dominant species in the shaft above 924 feet, had not been described before.

Planktonic foraminifera common to both the Caribbean and Victorian sequences show that these differences are probably not due to hiatuses, but are to be explained by the geographical factor. Some of the Caribbean zone fossils are absent in Victoria, or occur so rarely as to be useless as zonal indices. A suggested correlation of the Lakes Entrance Oil Shaft zones with those established by Bolli (1957*a*) in Trinidad and by Blow (1959) in Venezuela is shown in text-figure 10.

The degree of contemporaneity of the initial appearances of species or subspecies in widely separated areas can best be assessed by a comparison of the first occurrences of some well-established species.

A rapidly evolving series leading from *Globigerinoides triloba triloba* (Reuss) to *Orbulina universa* d'Orbigny has been identified from such widespread areas as Venezuela (Blow, 1956, 1959), the Mediterranean (Blow, 1957),



TEXT-FIGURE 10

A proposed correlation of the stratigraphic zones established in the shaft sequence with those by Bolli (1957) in the Cipero formation of Trinidad and by Blow (1959) in the Tocuyo and Pozon formations of Venezuela. This proposed correlation is based on the initial appearances of six planktonic species and subspecies in the three areas.

Trinidad (Bolli, 1957), New Zealand (Finlay, 1947; Hornibrook, 1958) and from the Australian Miocene (Jenkins, 1958). It can, then, be accepted that the successive members of this series ranged geographically from equatorial to mid-temperate latitudes and there is neither apparent reason to expect, nor any evidence in favour of significant diachroneity of the phylogenetic events (appearances and extinctions) marking the evolution of the series. Confirmation of the global simultaneity of these events can be adduced from comparison with ranges of unrelated forms. Thus, in the shaft samples, it is seen that *Globorotalia menardii praemenardii* Cushman and Stainforth which evolves from the unkeeled species *Globorotalia scitula praescitula* Blow makes its initial appearance just after that of *Globigerinoides bispherica* Todd and only 12 feet before *Candorbulina glomerosa curva* (Blow). In the Cipero formation, Bolli (1957*a*, fig. 18) shows the initial appearance of *Globorotalia menardii praemenardii* Cushman and Stainforth (= *Globorotalia archeomenardii* Bolli) as occurring just after that of *Globigerinoides bispherica* Todd, and at about the same time as *Candorbulina glomerosa curva* (Blow). In Venezuela, Blow (1959) has shown that *Globorotalia archeomenardii* Bolli evolves from *Globorotalia praescitula* Blow at the same time as the initial appearance of *Globigerinoides bispherica* Todd. Thus, it can be accepted that these closely successive events were contemporaneous and have world-wide significance.

Bolli (1957*a*, fig. 18) records the initial appearance of *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins) at the beginning of the *Catapsydrax stainforthi* zone in the Cipero formation. It is seen to make its first appearance after the extinction of *Globigerina ciperoensis*

ciperoensis Bolli, and after the initial appearance of *Globigerinoides triloba triloba* (Reuss). From the study of this subspecies in the Australian and New Zealand Tertiary, it is seen to occur much earlier than this. Thus Hornibrook (1957, table 1) records its initial appearance well before *Globigerinoides triloba* (Reuss), and Carter (1958*a*, table 3) shows it appearing just after *Globigerina ciperoensis ciperoensis* Bolli and before *Globigerinoides triloba* (Reuss). In the shaft it makes its appearance slightly before *Globigerina ciperoensis ciperoensis* Bolli and well before *Globigerinoides triloba triloba* (Reuss). It is therefore obvious that, if we have been identifying these forms accurately, there is a marked time discrepancy between the initial appearance of *Globoquadrina dehiscens dehiscens* (Chapman, Parr, and Collins) in the Australian and in the Trinidad regions. Specimens of this subspecies, including the holotype, have been examined at Melbourne, and later at Wellington, with Carter's and Hornibrook's assistance. Bolli (1957*a*) figures this subspecies and from his illustration (pl. 24, figs. 3–4) it would appear that all the investigators are in fact dealing with the same species. It follows from these distributions that the ancestor of this subspecies is probably to be found in the Australian rocks and later spread into the Trinidad region.

The last example to be considered is that of *Globorotalia barisanensis* LeRoy, first recorded from Sumatra. In the Cipero formation Bolli (1957*a*, fig. 18) shows its initial appearance occurring first before that of *Globigerinoides triloba triloba* (Reuss), but in the shaft sediments it occurs for the first time only 12 feet below the initial appearance of *Orbulina universa* d'Orbigny, much later than in Trinidad. Thus, there appears to be a time discrepancy between the initial appearance of this species in the two areas. It also follows that it is more likely that the ancestor of *Globorotalia barisanensis* LeRoy will be found in the Trinidad rocks. In the Cipero formation, in the time which elapsed between the initial appearance of *Orbulina universa* d'Orbigny and *Globorotalia menardii menardii* (d'Orbigny), the species *Globorotalia barisanensis* LeRoy evolved into the keeled *Globorotalia fohsi*-lineage (Bolli, 1957*a*), but in the shaft sediments within the time period mentioned *Globorotalia barisanensis* evolves into *Globorotalia mayeri* Cushman and Ellisor.

Besides using the vertical ranges of species and subspecies, it is also possible to derive useful stratigraphic information from certain broad morphological changes common to an entire generic plexus. For instance, the study of the attitude of coiling in *Globorotalia* shows that in the bottom half of the shaft sinistral and dextral specimens are equally frequent, whereas after a gradual change between 700–600 feet there occurs a preponderance of sinistrally coiled forms. A similar change to sinistral dominance takes place at about the same time in the Cipero formation of Trinidad (Bolli, 1950) and in the sediment of the United States Gulf Coast (Akers, 1955) which suggests that it was a widespread occurrence, thus having some importance in lower Miocene correlations.

CONCLUSION

At present it appears that the most reliable time marker for intercontinental correlation is the initial appearance of a planktonic foraminiferal species or subspecies which is a member of an established evolutionary lineage, the antecedent members of which were globally distributed. It is suggested that the only way possible (short of absolute dating) to check the validity of the appearances of these forms as accurate time markers is to compare two or more evolutionary series which were evolving at the same time, and see if the initial appearances of the various forms occur in the same order in the widely separated areas, as has been attempted in the foregoing pages.

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ABSTRACT: *Studies of the bathymetric distribution of planktonic foraminifera indicate that they are most abundant in the euphotic zone of the oceanic waters around Bermuda. Seasonal fluctuations in the relative and absolute abundances of fifteen species have been observed from 106 plankton samples, showing a regular succession in the foraminiferal populations.* Globorotalia hirsuta, G. truncatulinoides, Globigerina inflata *and* G. bulloides *were most abundant in winter and spring, when temperatures within the euphotic zone ranged between 18° and 23° C and salinities varied between 34.40‰ and 36.60‰.* Globorotalia menardii, Globigerinoides sacculifer *and* G. conglobatus *reached their maximum concentrations in summer and fall, when temperatures ranged between 23° and 27° C and salinities between 36.10‰ and 36.40‰. The oceanographic and paleoecologic implications of these observations are discussed for the northern Sargasso Sea.*

Ecology of Recent planktonic foraminifera:
Part 2 — Bathymetric and seasonal distributions in the Sargasso Sea off Bermuda

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INTRODUCTION

In this investigation the bathymetric and seasonal distributions of living planktonic foraminifera are described in the oceanic waters around Bermuda. Intensive sampling here has shown seasonal cycles that are of specific importance to foraminiferal population-growth studies and of general significance to interpreting their distribution patterns over a broad region of the northwestern Sargasso Sea. Accompanied by hydrographic observations, these analyses provide some insight into the foraminiferal life habits, some of which may prove useful for paleoecological interpretation of fossil assemblages.

Studies of bathymetric distribution require the use of quantitative opening-and-closing plankton samplers to obtain a series of samples at selected depth intervals without contamination from plankton living in overlying water strata. From such a series of tows taken at successive depths at a particular station, it is possible to ascertain whether or not there exist (1) any optimum depth habitat or stratum of greatest concentration of each species, where, presumably, active growth and reproduction take place, (2) any species stratification with depth, (3) any effect of temperature, salinity, light, etc. as possible limiting factors in the vertical distribution of each species, and (4) any correlation between morphological variations (in size, shape, thickness, color of protoplasm) and depth.

Seasonal variations in foraminiferal distribution can be observed when samples are taken at frequent intervals at designated locations. As there is practical difficulty in obtaining plankton samples on a seasonal basis from a large number of oceanic stations, knowledge of synoptic conditions and seasonal fluctuations of marine plankton remains fragmentary and obscure.

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The following persons took part in the plankton collecting at one time or another: Drs. Robert Bieri, David Krinsley, David W. Menzel, Robert J. Menzies, William H. Sutcliffe, Jr., and the writer. Many thanks are due to Drs. William H. Sutcliffe, Jr., director, and David W. Menzel of the Bermuda Biological Station for their warm-hearted cooperation during the stay of the Lamont group at the Station. This project was made possible through support from grants from the Rockefeller Foundation (RK 57076) and the National Science Foundation (NSF G-9557). Indirect aid, which made

TABLE 1

COLLECTIONS OF PLANKTON SAMPLES FROM BERMUDA WATERS EMPLOYED IN PRESENT INVESTIGATION

Expedition	No. of plankton samples	Date of collection
New York Zoological Society	17	April to September, 1929
New York Zoological Society	25	May to September, 1930
New York Zoological Society	20	June to October, 1931
Lamont Geological Observatory	3	August, 1955
Lamont Geological Observatory	10	January, 1957
Bermuda Biological Station	31	December, 1957, to January, 1959
	Total 106	

possible the collection of plankton samples within projects of broader scope, was given by Atomic Energy Commission Contract No. 8T-(30-1)-2078 to the Bermuda Biological Station.

PREVIOUS INVESTIGATIONS

Our scanty knowledge of the vertical distribution of planktonic foraminifera is largely due to the difficulty of obtaining quantitative serial samples at different depth intervals, and the intricacy of the special plankton collecting gear used. Field studies have been conducted by Lohmann (1920), Schott (1935), Phleger (1945, 1951) and Bradshaw (1959).

Lohmann (1920) examined the plankton samples collected in vertical tows by the *Deutschland* Expedition of 1911 in the North and South Atlantic. He found that the richest concentration of globigerinids occurred in the upper one hundred meters of water and that below this depth they were significantly less abundant.

Schott (1935) made detailed studies of foraminiferal distribution in the equatorial Atlantic from 141 plankton samples collected by the *Meteor* Expedition of 1925–1927. The plankton samples were taken with a Hansen closing net (70-micron mesh-size) at various depth intervals to 1000 meters, although the 0–100 meters depth range was emphasized. His data clearly indicate that the planktonic foraminifera were preponderantly present in the upper 100 meters of water. A sharp decrease in their abundance was evident below this depth, although specimens were found at all the depths sampled.

Phleger (1945) made preliminary investigations of the vertical distribution of planktonic foraminifera in the North Atlantic. Fourteen plankton samples from five stations were obtained with Clarke-Bumpus plankton samplers with 70-micron mesh-size silk nets. Although the data were limited and inconclusive, a grouping of the fourteen samples into three depth intervals, i.e., 75–100 meters, 325–500 meters, and 650–1000 meters, shows that there were a mean number of 0.8, 0.5 and 0.7 specimens per cubic meter of water in the respective depth zones.

Phleger (1951) obtained 93 quantitative plankton samples from twenty-seven stations in the northwest Gulf of Mexico. Living planktonic foraminifera were present in all the samples from depths of 20 to 2000 meters. Between 20 and 145 meters depth, there was a mean number of 29 foraminiferal specimens per cubic meter of water for the 42 plankton tows. Between 175 and 2000 meters depth, a mean number of 12 specimens per cubic meter of water was encountered for 37 tows. Thus the density of planktonic foraminifera in the upper 200 meters was two to three times that below 200 meters depth. The vertical decrease was on a smaller order than that observed by Lohmann (1920) and Schott (1935).

Bradshaw (1959) presented data on the vertical distribution of planktonic foraminifera from 61 samples taken from one locality in the eastern Pacific. He concluded that "(1) the samples taken directly from the sea surface contain fewer specimens, in most of the tows, than those taken slightly deeper, (2) the highest concentrations of foraminifera occur between 6 to 30 meters in most tows. In no tow does the greatest concentration occur below 100 meters, (3) the depth of greatest decrease in number per cubic meter occurs between 50 and 100 meters in most tows, and (4) relatively low concentrations of specimens were noted below 200 meters."

These previous studies agree with each other in that the greatest concentration of the planktonic foraminifera was encountered in the upper 200 meters of water, and that below this epiplanktonic zone they decreased significantly in abundance. It should be noted that Emiliani (1954), who inferred depth habitats of the foraminiferal species from dead assemblages by means of oxygen-isotope ratios, had come to the similar conclusion that planktonic foraminifera are restricted to the upper 220 meters of water.

No previous study of the seasonal distribution of planktonic foraminifera is known to the writer. This is probably due in part to lack of adequate seasonal coverage of samples at any particular oceanic station.

METHODS OF STUDY.

This study is based on a total of 106 plankton samples collected in the oceanic waters southeast of Bermuda. Table 1 refers to the institutions sponsoring the plankton-collecting programs, the number of samples examined and the dates of their collection.

TABLE 2

Ten quantitative plankton samples obtained on January 23, 1957, from a series of depth ranges with a one-half meter opening-and-closing plankton net in Bermuda waters (32°07.5′ N and 64°39′ W).

Sample no.	Date	Time	Total time of tow (minutes)	Depth range of tow (meters)	Volume of water filtered (m^3)	Displacement volume of total plankton (ml/1000 m^3)	Temperature (°C) at maximum depth	Salinity (‰) at maximum depth
1	1/23/57	0934–0954	20	0–25	242	40.5	20.7	36.66
2	,,	1043–1054	11	25–50	124	316.0	20.8	36.67
3	,,	1137–1156	19	50–75	198	20.2	20.5	36.61
4	,,	1244–1301	17	75–100	220	36.2	20.4	36.59
5	,,	1404–1411	7	100–150	108	55.6	19.4	36.59
6	,,	1500–1535	35	150–200	91	32.9	18.2	36.49
7	,,	1723–1748	25	200–300	213	9.4	18.2	36.48
8	,,	1859–2040	101	700–1000	361	6.9	7.1	35.10
9	,,	2122–2150	28	0–50	269	59.5	—	—
10	,,	2238–2255	17	50–100	163	42.9	20.0	36.68

New York Zoological Society samples

The early series of samples were obtained during the months of April to September of 1929, May to September of 1930, and June to October of 1931, by the Bermuda Oceanographic Expedition under the leadership of Dr. William Beebe, New York Zoological Society. These samples came from an area eight miles in diameter, the center of which was at 32°12′ N. latitude and 64°36′ W. longitude and about 9 miles south-southeast of Nonsuch Island (text-fig. 1). The method of work, collecting apparatus, the depth, date, time, and duration of each plankton haul were described by Beebe (1931, 1932). The plankton sampling equipment was similar to that used on the *Arcturus* Expedition of 1925 by the New York Zoological Society and details of its workings were recorded by Beebe (1926) and Tee-Van (1926).

More than 1300 plankton samples were collected by the Bermuda Oceanographic Expedition. Many of these samples were later lumped with others taken at approximately the same time of day and week and depth range. This was done by earlier investigators who apparently were searching for fishes and other rarer organisms in samples having similar depth ranges. Thus the 62 samples used in the present study originally represented two hundred hauls. Seventeen of these samples were taken in 1929, twenty-five in 1930, and twenty in 1931.

A one-meter diameter Michael Sars plankton net (Tee-Van, 1926) was employed, having a total length of 4.80 meters and consisting of three different filtering sections. The forward section had a mesh diameter of 10 mm. and a length of 50 cm.; the middle part was made of bolting cloth with a mesh diameter of 569 microns and a length of 100 cm.; and the after-section was made of bolting cloth with a mesh diameter of 366 microns and a length of 300 cm. Since the main objective of the expedition was the study of fishes, nets with fairly coarse-meshed front sections were used. Relatively large planktonic foraminifera were found in all samples. However, many small-sized individuals certainly could have passed through the first two filtering sections of the net and probably also through the after-section.

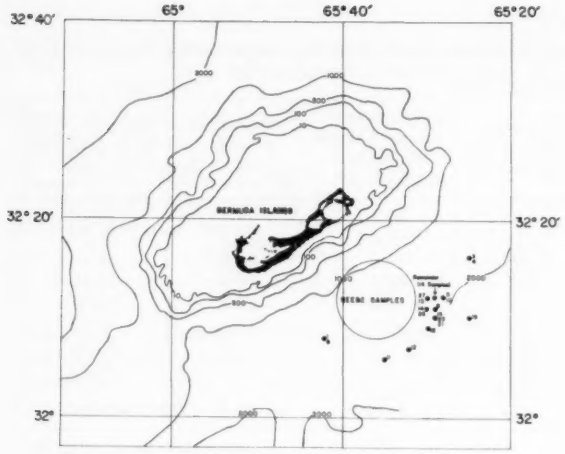
Six one-meter nets were attached in series to the wire cable at equal distances and were lowered so that the lowest and uppermost nets towed at 1000 and 500 fathoms, respectively. The duration of towing at these maximum depths for the individual nets was between four and five hours. No opening-and-closing devices were used to obtain samples uncontaminated from the overlying waters. Thus, in the present study no attempt was made to use these samples for studying variations in vertical distribution of the planktonic foraminifera. A quantitative comparison of their absolute abundances could not be made, because no flow meters were used to measure the amount of water strained through each net. Nevertheless, the samples proved valuable in studying seasonal variations in the species composition of the foraminifera.

Lamont samples

Three plankton samples were collected in Bermuda waters on August 25 and 26, 1955 during the seventh cruise of R/V *Vema*. The results on the areal distribution of the planktonic foraminifera in the western North Atlantic gathered during this cruise have been reported by Bé (1959).

Ten quantitative opening-and-closing plankton tows were taken on January 23, 1957, in Bermuda waters at about 32°07′ N. latitude and 64°39′ W. longitude (Table 2). The field sampling program was carried out in cooperation with the Bermuda Biological Station.

In view of the larger ecologic fluctuations generally present in the surface layers, the upper 200 meters were sampled at smaller intervals than the deeper waters. The following depth intervals were sampled: 0–25 meters, 25–50 meters, 50–75 meters, 75–100 meters, 100–150 meters, 150–200 meters, 200–300 meters, and 700–1000 meters during daylight hours, and 0–50 meters and 50–100 meters during night hours. Unfortunately, no sample could be taken between 300 and 700 meters depth, so that the results must be interpolated for this depth range.



TEXT-FIGURE 1

Location of stations of plankton samples. Numbered dots indicate samples collected between November, 1957, and January, 1959. Large circle designates area where New York Zoological Society samples were collected. Depth contours in fathoms.

The plankton samples were obtained with a 200-micron mesh-size (no. 8, or 86 meshes per inch) nylon net, which consisted of a cloth collar about 50 cm. long, a filtering net section 240 cm. long, and a cod end 10 cm. long, a total length of three meters. The opening-and-closing mechanism with the releasing device and messengers used were basically similar to those described by Leavitt (1935, 1938).

The volume of water filtered was measured by an Atlas flow meter. The depth range of each plankton tow was determined by a bathygraph (Beebe, 1931). Each sample was preserved in 5 per cent formalin buffered by hexamethylene-tetramine. Temperature and salinity data were obtained with Nansen bottles for each of the depth intervals sampled.

Bermuda Biological Station samples

Thirty-one quantitative plankton samples were collected approximately biweekly from December, 1957, to January, 1959, in Bermuda waters (Table 3). Collections were made 15 miles southeast of Bermuda (text-fig. 1) in about 1500 fathoms of water. They were obtained by Dr. David W. Menzel on board the R/V *Panulirus*, stationed at and operated by the Bermuda Biological Station.

The majority of the samples were one-half-hour tows, taken obliquely with nets lowered and raised at a uniform rate through the upper 500 meters of water. The nylon net had a 75 cm. diameter face opening and an average aperture size of 0.366 mm. (no. 2 mesh, or 54 meshes per inch). A flow meter was placed within the face opening of the net to record the volume of water filtered. All tows were completed during daylight hours, so that any effect of diurnal vertical migrations was minimized.

These samples represent the first opportunity of studying any seasonal cycles in living populations of planktonic foraminifera for an uninterrupted 14-month period. It is a welcome fact that these samples came from a single locality in the middle latitudes of the western North Atlantic, where significant seasonal fluctuations in hydrographic conditions occur. The Bermuda region is an ideal one for the study of foraminiferal species under a wide variety of ecologic environments.

BATHYMETRIC DISTRIBUTION

Lamont samples, January, 1957

The following fourteen species were observed in the plankton samples collected in January, 1957 in order of decreasing abundance:

Globorotalia truncatulinoides (d'Orbigny)
Globigerinella aequilateralis (Brady)
Pulleniatina obliquiloculata (Parker and Jones)
Globigerina bulloides d'Orbigny
Globigerinoides ruber (d'Orbigny)
Globigerina eggeri Rhumbler
Globorotalia hirsuta (d'Orbigny)
Globigerinita glutinata (Egger)
Globorotalia menardii (d'Orbigny)
Globigerina inflata d'Orbigny
Hastigerina pelagica (d'Orbigny)
Orbulina universa d'Orbigny
Globigerinoides sacculifer (Brady)
Globorotalia punctulata (d'Orbigny)

The bathymetric distributions of the individual and total foraminiferal species indicated predominant concentrations in the upper 200 meters (text-fig. 2). The richness of the upper six tows contrasted sharply with the scarcity of foraminifera in the two deeper samples. Maximal abundances appeared between 100–150 meters and 25–50 meters.

These observations are in general agreement with those by Lohmann (1920), Schott (1935), Phleger (1945, 1951), and Bradshaw (1959). It is probable that these foraminifera prefer to live in the euphotic zone because of their dependence upon phytoplankton as a source of food.

Variation in number of species with depth

All fourteen species were present in the upper 100 m. of water, but the number of species decreased with depth. The species absent in the deeper tows were those that also appeared in small numbers in near-surface waters (text-fig. 2). It is not possible at this time to determine whether the absence of certain species at the greater depths can be attributed to either their affinity to shallower waters or to their initially small standing crop. From these observations there is no direct evidence of any stenobathic species or any species stratification at different depth levels.

TABLE 3

Quantitative plankton samples collected in Bermuda waters between November, 1957, and January, 1959, by Bermuda Biological Station. Location of samples shown in text-figure 1.

Sample no.	Date	Time	Depth range of tow (m)	Volume of water filtered (m^3)	Total plankton displacement volume (ml/1000 m^3)	Depth of water (fms)	Surface temp. (°C)	Surface salinity (‰)	No. of planktonic foraminifera per 1000 m^3 of water
1	12–3–57	14:30	0–500	648	17	1700	—	—	212
2	1–14–58	10:12	0–1500	1839	16	1550	20.45	36.43	—
3	1–14–58	10:15	0–500	784	18	1550	20.45	36.43	—
4	1–30–58	10:30	0–500	816	17	1550	—	—	192
5	2–11–58	17:43	0–500	720	36	1550	19.01	36.45	626
6	2–22–58	10:06	0–500	425	24	1550	18.62	—	1608
7	3–25–58	13:20	0–500	232	170	1500	18.33	36.53	2160
8	4–21–58	17:25	0–500	244	210	1500	—	—	230
9	4–29–58	15:25	0–500	652	43	1550	—	—	636
10	5–2–58	15:45	0–1500	555	3	1620	20.24	36.47	814
11	5–19–58	10:45	0–500	410	14	1700	21.30	36.45	234
12	6–4–58	10:08	0–500	519	11	1550	24.04	36.54	208
13	6–18–58	12:00	0–500	510	25	1600	24.05	36.18	620
14	7–2–58	11:20	0–500	457	20	1600	25.97	36.08	718
15	8–5–58	16:00	0–500	611	14	1600	27.76	36.18	298
16	8–11–58	11:00	0–100	310	45	1550	—	—	1288
17	8–11–58	15:50	0–200	321	12	1550	—	—	254
18	8–18–58	10:45	0–500	516	27	1650	28.54	36.49	710
19	8–30–58	11:13	0–500	553	17	1700	28.29	36.34	271
20	9–15–58	10:25	0–500	584	19	1050	27.01	36.06	164
21	9–16–58	13:45	0–100	245	21	1550	—	—	783
22	9–16–58	14:20	0–200	306	13	1550	—	—	145
23	9–16–58	14:55	0–300	413	10	1550	—	—	135
24	9–16–58	15:35	0–400	498	13	1550	—	—	269
25	10–2–58	10:55	0–500	542	19	1550	26.99	36.05	1513
26	11–1–58	10:55	0–500	423	10	1500	24.43	36.23	459
27	11–14–58	11:00	0–500	620	28	1500	23.11	36.56	447
28	12–2–58	12:00	0–500	610	12	1600	23.49	36.37	193
29	1–2–59	10:30	0–500	612	21	1600	21.23	36.41	1350
30	1–2–59	10:30	0–500	370	18	1600	21.23	36.41	676
31	1–16–59	14:00	0–500	650	—	1550	20.31	36.46	1357

Variations in size and thickness of tests

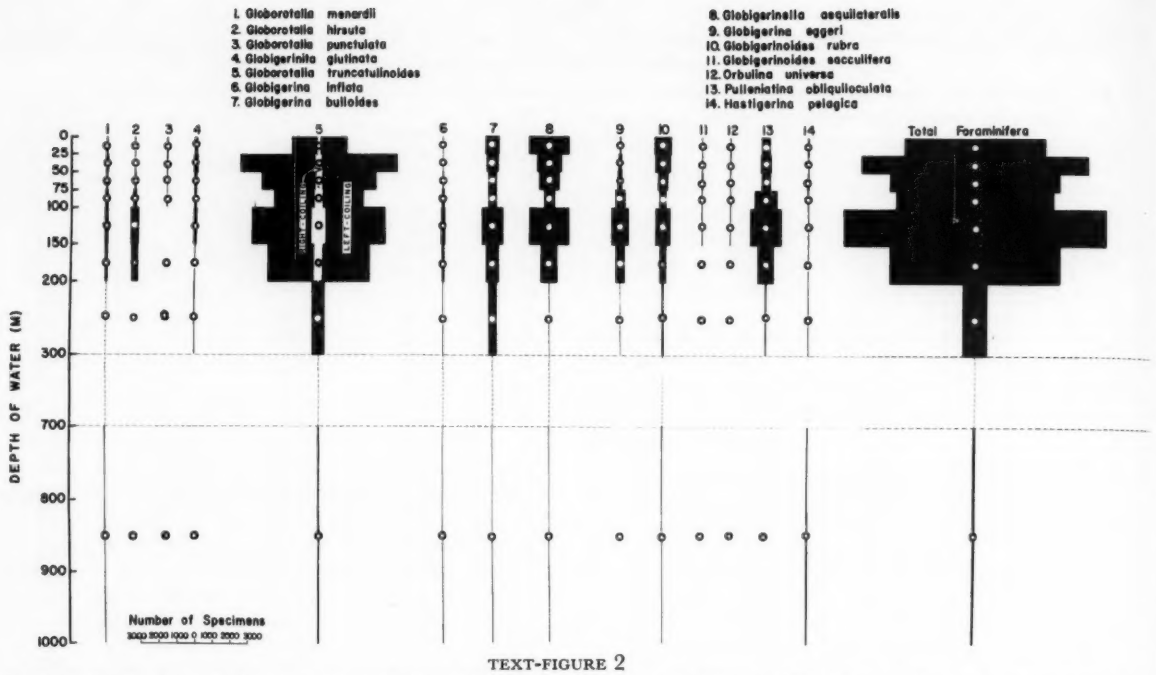
Although no precise measurements have been made on variations in size and thickness of foraminiferal tests with depth, it has been observed that small, thin-shelled foraminifera are proportionately more abundant in the surface waters (0–25 m.) than at greater depths. Large, thick-shelled specimens are generally more abundant in the deeper waters (below 150 m.). Such relationships are best illustrated by *Globorotalia menardii* and *Sphaeroidinella dehiscens*. The former shows selective thickening of a calcite crust on the earlier chambers of the last whorl, a characteristic feature observed only in specimens caught in deep tows (300 meters or deeper). Large thick-shelled specimens of *S. dehiscens* are also found in deep tows only.

Spines

It is of interest to note that not all species of the Globigerinidae bear spines as commonly supposed. *Globigerina inflata*, *G. eggeri*, *Globigerinita glutinata*, *Pulleniatina obliquiloculata* and *Candeina nitida* are conspicuous for their lack of spines throughout their life cycles. *Globigerina bulloides*, *G. pachyderma*, *Globigerinoides ruber*, *G. sacculifer*, *G. conglobatus*, *Orbulina universa*, *Globigerinella aequilateralis*, *Sphaeroidinella dehiscens* and *Hastigerina pelagica* generally have spines in their juvenile stages, but either lose or have less of them in the mature stages. The absence of spines at some stage or throughout the life cycle of these species is real and not due to breakage during plankton-towing, because in the latter event the broken spine bases would be apparent. Also, the first group of five species mentioned are always spineless, even when they occur together with species having spines. In contrast to the presence of spines in many species of the Globigerinidae, all species of the Globorotaliidae are spineless.

Empty tests

Empty tests increased in number with depth. They were extremely rare (less than 0.1%) between 0–150 meters, but in the 150–200 meters, 200–300 meters and 700–1000 meters tows they constituted approximately



TEXT-FIGURE 2

Vertical distribution of planktonic foraminifera in Bermuda waters in January, 1957. The number of specimens per 1000 m^3 of water of each species is plotted horizontally at the midpoints (white dots) of the sampled depth ranges. No samples were taken between 300 and 700 meters.

1%, 13% and 35%, respectively, of the total tests of planktonic foraminifera. The small number of empty tests in the euphotic zone may be remnants after the reproductive process or egested products of predators. The increasing proportion of empty tests in the deeper tows suggests that they were sinking at a relatively faster rate than the living specimens.

Color of protoplasm

The color of the protoplasm of several species showed variations with depth and time of day. *Globorotalia truncatulinoides*, *G. hirsuta*, *Globigerina inflata*, *G. bulloides*, *G. eggeri*, *Globigerinella aequilateralis*, and *Pulleniatina obliquiloculata* generally contained olive to dark green protoplasm within the tests encountered in the upper 200 m. tows. However, the frequency of specimens with whitish protoplasm increased in the deeper tows. This perhaps may be due to lack of phytoplankton food or deficiency of zoochlorellae-zooxanthellae symbionts in these deeper tows. In contrast, the green pigmentation of planktonic foraminifera in the euphotic zone may be attributed to ingested phytoplankton or presence of symbionts.

There is also visible contrast between the olive-green protoplasm of specimens caught in *day* tows of near-surface waters and the yellow-green protoplasm of specimens in *night* tows of equivalent depth. This color change in the protoplasm, according to Charles Yentsch (personal communication), is also observed in marine phytoplankton and is due to the dominance of caratenoid pigments relative to the nightly breakdown of chlorophyll pigments. If this color change occurs diurnally, it is likely to be due to changes in the pigmentation of zoochlorellae symbionts. *Hastigerina pelagica* is a notable exception to these observations in that its protoplasm was invariably white or yellow-brown with small bright red speckles interspersed.

Diurnal variations in standing crop

Comparison of the absolute abundance of planktonic foraminifera between 4-day and 2-night tows collected between 0–100 meters on January 23, 1957, showed a significant decrease in their abundance in the night samples (Table 5).

This observation is made on a very limited number of samples, but it is noted here in the light of a similar and more detailed finding by Rhumbler (1911). In his monograph "Die Foraminiferen (Thalamophoren) der Plankton Expedition," an unexplained chart was included which clearly showed the increased number of planktonic foraminifera in the day tows as compared to the night tows (text-fig. 3). Bradshaw (1959) made

TABLE 4

Presence and absence of spines among planktonic foraminifera

Family Globorotaliidae	
Globorotalia menardii	Spines absent throughout life cycle
Globorotalia tumida	
Globorotalia hirsuta	
Globorotalia punctulata	
Globorotalia truncatulinoides	
Globorotalia scitula	
Family Globigerinidae	
Globigerina inflata	Spines absent throughout life cycle
Globigerina eggeri	
Pulleniatina obliquiloculata	
Globigerinita glutinata	
Candeina nitida	
Globigerina pachyderma	Spines present and well-developed in juvenile stages, but less well-developed and frequently absent in mature stages
Globigerina bulloides	
Globigerinella aequilateralis	
Hastigerina pelagica	
Globigerinoide ruber	
Globigerinoides sacculifer	
Globigerinoides conglobatus	
Orbulina universa	
Sphaeroidinella dehiscens	

similar analyses of his data for the North and equatorial Pacific and noted that "the ratio of Night/Day hauls in all cases is less than 1, indicating that there is greater concentration at the surface during the day. Analysis shows that surface foraminifera during the day are generally more abundant than they are at night, but in the deep samples the night catches average more than the day samples. This suggests that foraminifera ascend to the surface during the day and descend at night."

Although no conclusive explanation can be offered at this time, two possible reasons for the significant reduction in foraminiferal numbers at night may be mentioned. First, there may be a considerable vertical "migration" upwards during the day and downwards during the night. The observed differences in abundance between day and night tows indicate that any downward transport must go well below 200 meters depth and involve a considerable percentage of the planktonic foraminifera. One can speculate that the presence of zooxanthellae (Rhumbler, 1900, 1911) and the requirement of plant food might induce the planktonic foraminifera to seek progressively shallower depths during daylight hours. Second, there may be a direct connection between the relative poverty of planktonic foraminifera and the rise of the "scattering layer" during the early night hours. It is conceivable that during these hours the animals that rise to surface waters are feeding upon the planktonic foraminifera. This latter hypothesis does not require a diurnal vertical migration of the planktonic foraminifera, but it does not explain how they can maintain a healthy population balance with daily population reduction of up to 50%. No ingested planktonic foraminiferal tests have been found in any significant numbers in the guts of other zooplankton.

TABLE 5

Reduction in concentration of planktonic foraminifera in night tows as compared to day tows in Bermuda waters

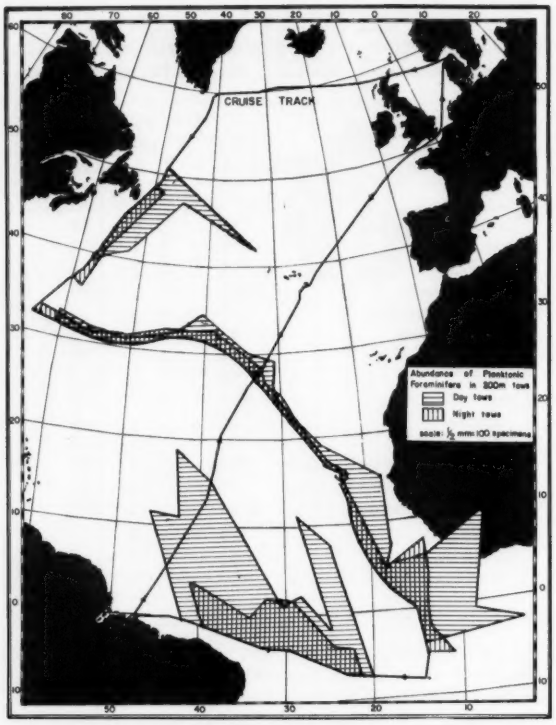
Species	Mean number of specimens per 1000 m³	
	Day tows, 0–100 meters (0934–1301 hour)	Night tows, 0–100 meters (2122–2255 hour)
Globorotalia menardii	98	42
G. hirsuta	79	3
G. punctulata	2	0
G. truncatulinoides	5833	5088
Globigerinita glutinata	163	17
Globigerina inflata	45	3
G. bulloides	554	38
G. eggeri	168	3
Globigerinoides ruber	665	99
G. sacculifer	18	0
Orbulina universa	20	14
Pulleniatina obliquiloculata	700	134
Hastigerina pelagica	27	14
Globigerinella aequilateralis	1320	687
Total planktonic foraminifera	9692	6142

Correlations with ecological factors

The actual temperatures observed at the maximum depths of each depth interval sampled are listed in Table 2. The vertical temperature profiles for January and August reproduced in text-figure 4 are from Fuglister (1947). Winter waters are nearly isothermal to a considerable depth; January average temperatures are about 20°C at the surface and about 18°C at 300 meters. During spring and summer warming of surface waters, a seasonal thermocline is developed at about 100 m. which separates the shallow, warm layer with surface temperatures as high as 27°C from a deep, cool layer with temperatures of about 18°C at 300 meters.

Comparing the vertical distributions of planktonic foraminifera (text-fig. 2) with the average January temperatures of Bermuda waters (text-fig. 4), we can conclude that the majority of the foraminifera in these waters lived at temperatures between 18° and 20°C. Although a sharp decrease in concentration of the planktonic foraminifera was observed below 200 meters depth, there was no correspondingly sharp change in temperature at this depth. Consequently, it is inferred that in this case temperature was not the prime factor governing the vertical distribution of planktonic foraminifera. The relatively deep, isothermally cold waters in January may explain the absence of any species stratification with depth. Any species stratification, if influenced primarily by temperature differences, would perhaps be expected in August.

As planktonic foraminifera probably possess symbiotic zooxanthellae and rely upon phytoplankton as a food source, the light required for photosynthesis by the



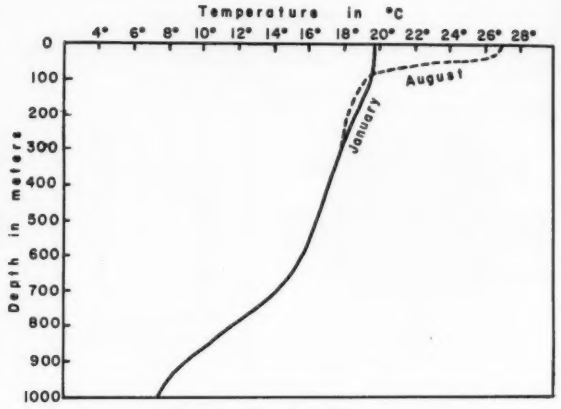
TEXT-FIGURE 3

Rhumbler's chart showing the increased number of planktonic foraminifera in day tows as compared to night tows taken by the German *National* Expedition, July–September, 1898 (modified after Rhumbler, 1911).

latter seems to be a more critical factor than temperature in limiting these foraminifera to the upper 200 m. of water. The depth limit at which photosynthesis by phytoplankton practically ceases (compensation depth) is at or less than 100 m. depth in the Sargasso Sea region (Menzel and Ryther, 1960, fig. 1). Below this level there is less than one per cent of the incident radiation and this is accompanied by an abrupt decrease in phytoplankton. The present field evidence that the planktonic foraminifera are predominantly restricted to the upper 200 m. agrees generally with the depth limit of the euphotic zone.

SEASONAL DISTRIBUTION

One hundred and six plankton samples collected over a period of years were available for determining the seasonal distribution of planktonic foraminifera in Bermuda oceanic waters (Table 1). The differences in sampling procedures between these series of tows do not permit quantitative comparisons of *absolute* abundance of the foraminifera. Such studies could only be made for the latest series of samples (1957–1959), when flow meters and a standard collecting method were used.



TEXT-FIGURE 4

Average temperatures of Bermuda waters in January and August (modified from Fuglister, 1947).

However, comparisons of the *relative* abundance between all these plankton tows are valid, since nets of approximately similar mesh were employed. A study of the species composition does not necessarily require quantitative data on the actual foraminiferal concentrations.

Absolute abundance

The absolute abundances of the various species of planktonic foraminifera in Bermuda waters during the 14-month period from December, 1957, to January, 1959, are shown in text-figure 5. They correspond in general with the charts showing seasonal variations in their relative abundances (text-figs. 6–10). The months of December, 1957, and December, 1958, indicated very small concentrations and relatively few foraminiferal species. These low absolute abundances affect the corresponding relative abundances of these species, making the latter not so reliable when used in comparison with other months that have higher foraminiferal concentrations and a larger number of species.

A maximum of fifteen species are known to occur in the Bermuda region. All of them were figured by Bé (1959) and are listed here in order of general decreasing abundance and year-round occurrence in Bermuda waters.

Hastigerina pelagica (d'Orbigny)
Globigerinella aequilateralis (Brady)
Orbulina universa d'Orbigny
Globigerinoides ruber (d'Orbigny)
Globorotalia hirsuta (d'Orbigny)
Globorotalia truncatulinoides (d'Orbigny)
Globigerinoides sacculifer (Brady)
Globigerinoides conglobatus (Brady)
Globigerina inflata d'Orbigny
Globigerina bulloides d'Orbigny
Globorotalia menardii (d'Orbigny)
Pulleniatina obliquiloculata (Parker and Jones)
Globorotalia punctulata (d'Orbigny)
Globigerinita glutinata (Egger)
Globigerina eggeri Rhumbler

TABLE 6

Correlation between seasonal distributions of planktonic foraminifera and surface-water temperatures and salinities in Bermuda waters.

	Period of occurence	Range of surface temperatures	Range of surface salinities
Group I – Temperate species *Globorotalia hirsuta* *G. truncatulinoides* *Globigerina inflata* *G. bulloides*	January through May, with peak abundances in February and/or March	18.5° to 23°C	36.40‰ to 36.60‰
Group II *Orbulina universa* *Hastigerina pelagica* *Globigerinella aequilateralis* *Globigerinoides ruber* *Globorotalia punctulata*	Common throughout the year, but peak abundances generally during summer and fall	18.5° to 27°C, but more common between 23° and 27°C	36.10‰ to 36.60‰
Pulleniatina obliquiloculata *Globigerinita glutinata* *Globigerina eggeri*	Rare throughout the year		
Group III – Subtropical species *Globigerinoides sacculifer* *G. conglobatus* *Globorotalia menardii*	June to December, with peak abundances around October	23° to 27°C	36.10‰ to 36.40‰

Occasionally, *Hastigerinella rhumbleri* Galloway is present in deep tows. As intergrading forms exist between this and *Hastigerina pelagica*, they are considered to belong to the same species and, therefore, are grouped together under *H. pelagica*.

The highest concentration of 2160 specimens of *total* planktonic foraminifera per 1000 m^3 of water was found in March, 1958. This coincided or followed soon after the spring bloom of phytoplankton in this area. The months between April and September had relatively low concentrations of about 500 specimens per 1000 m^3 of water. In October, 1958, a secondary peak occurred with foraminiferal concentrations as high as 1500 specimens per 1000 m^3 of water. This was followed by a minimum concentration of about 200 specimens per 1000 m^3 of water in December, 1958. A similar, low concentration also appeared in December, 1957.

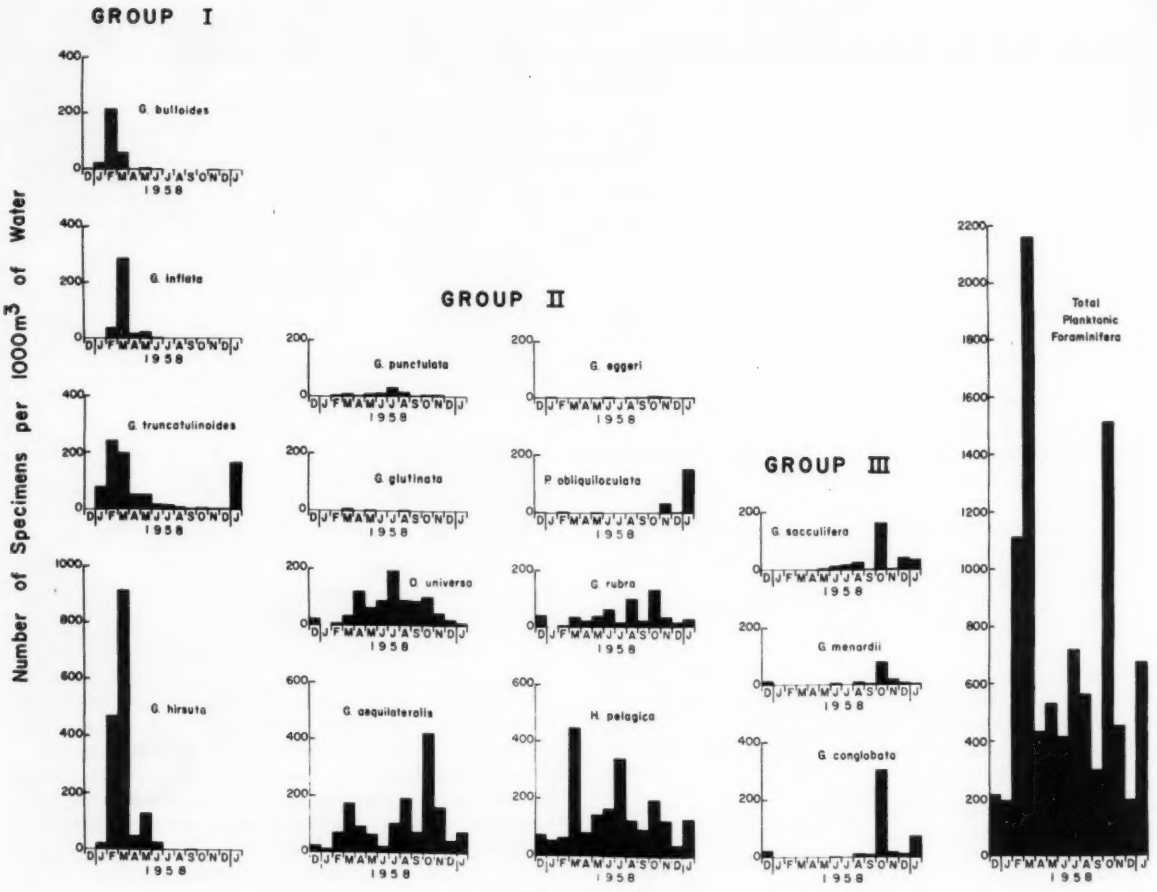
Relative abundance of individual species

The seasonal variations in relative abundance of the foraminiferal species (text-figs. 6–10) show that they can be grouped into three broad categories based on magnitude and length of their occurrences. Group I includes cold-stenothermal species that compose the greatest part of the total foraminiferal population in Bermuda waters from January to March; their population growth is largely confined between January and June, while between July and December they are rare or absent. Group II consists of (a) eurythermal species that are abundantly present in Bermuda waters throughout the year, with maximum abundances occurring in the warmer months, and (b) species that are never abundant throughout the year and are more frequently found in the warmer months. Group III comprises warm-stenothermal species that are generally restricted to the warmer months between June and December and occur in peak abundances in October; they are absent or rare from January to June. The most striking feature of the seasonal variations in the foraminiferal species composition is the distinct contrast between the alternating occurrences of Group I from January to June and of Group III from June to December. These three categories are listed in Table 6 and text-figure 10.

Group I includes species that are characteristically abundant in mid-latitudes of the North Atlantic (Phleger, Parker, Peirson, 1953; and Phleger, 1954). These may also be termed "temperate," or more specifically "warm-temperate," species that inhabit regions with annual means somewhat below 20°C, where winter temperatures fall below 20°C (but not usually below 10°C) and summer temperatures have a typical range from 16° to 25°C (Stephenson, 1947).

Group III includes species that are characteristically abundant in low latitudes and that are termed "tropical-subtropical" species under Stephenson's definition, because they inhabit regions with mean annual surface temperatures of 25°C or more, where winter temperatures are somewhat below 20°C and summer temperatures 25°C or more.

Bermuda waters have a mean annual surface temperature of 22.5°C (U. S. Coast and Geodetic Survey, 1951). In 1958, the winter minimum was 18.3°C and the summer maximum was 28.5°C (text-fig. 11). Thus, according to Stephenson, Bermuda is intermediate between the



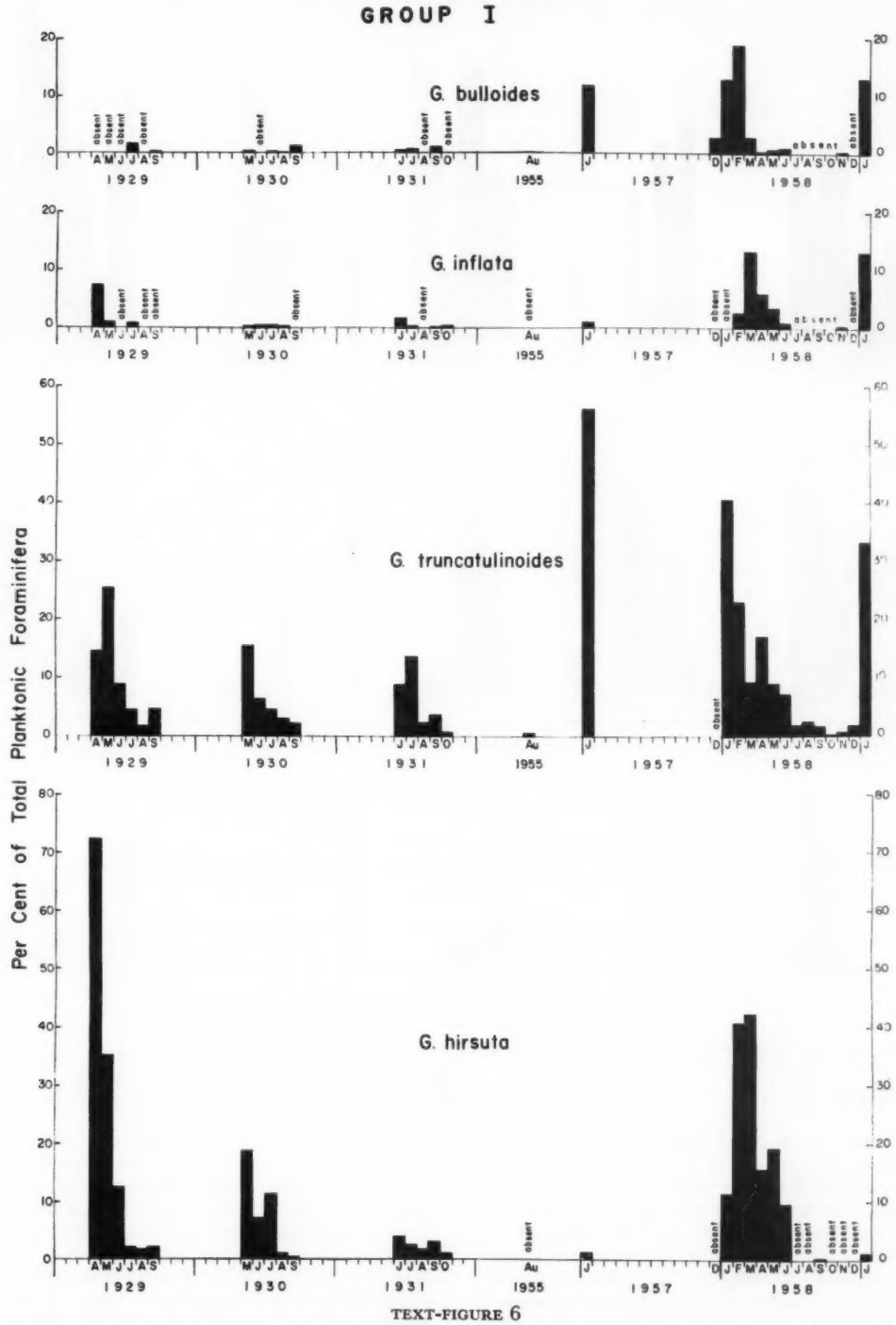
TEXT-FIGURE 5

Absolute abundance of planktonic foraminifera in Bermuda waters from December, 1957, to January, 1959.

warm-temperate and the subtropical regions. This view agrees well with the alternating peak occurrences of Group I (temperate) species of planktonic foraminifera in winter and spring and of Group III (subtropical) species in summer and fall (text-figure 10). It is of interest to note that the generally inverse proportions of temperate and subtropical foraminifera during the 12-month period of 1958 are very similar to those noted in 1929, 1930, and 1931, indicating the probability that such seasonal variations have been fairly regular during the past 30 years.

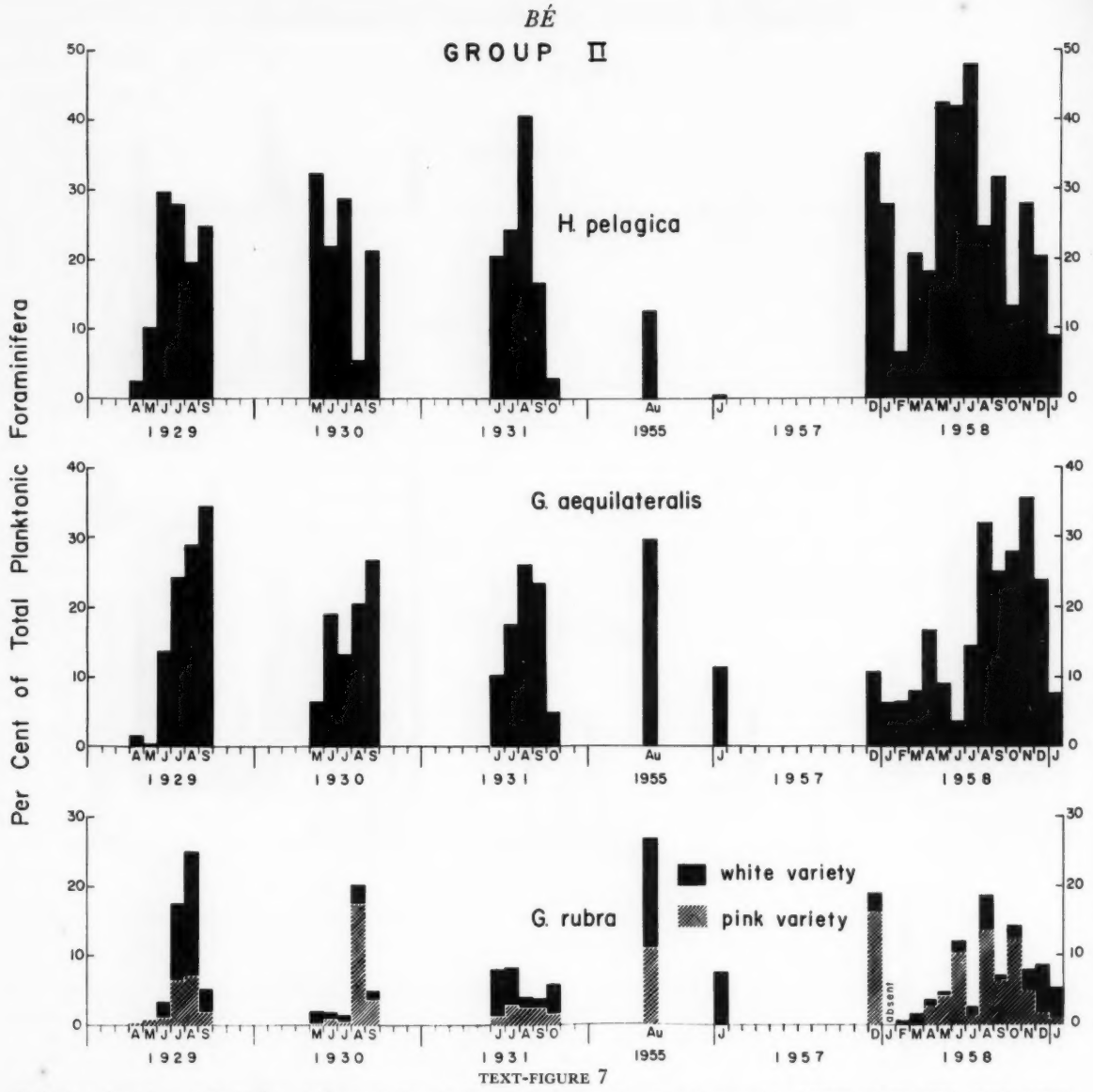
Some specific observations may be noted with regard to the seasonal variations in the color of the test of *Globigerinoides ruber* and the coiling direction of *Globorotalia truncatulinoides*. *G. ruber* derives its name from its characteristically pink to ruby-colored test. The color is generally more intensely pink in the early-formed chambers and is faded or colorless in the last-formed chambers. Specimens of *G. ruber* with completely white or colorless tests also occur together with pink specimens in the same waters. However, the number of individuals with pink tests is proportionally higher in the summer months, whereas they are rare or absent in the winter months between January and March. Specimens of *G. ruber* with white tests are present throughout the year, although they are lower in frequency in the winter months. Thus, the occurrence of pink tests of *G. ruber* appears to indicate more marked seasonal preference for warmer waters than individuals with white tests (text-fig. 7).

Left- and right-coiling individuals of *Globorotalia truncatulinoides* also show seasonal trends in their occurrences. The relative abundance of these two varieties in Bermuda waters is shown in text-figure 12a. In the local bottom sediments, left-coiling tests are more abundant than right-coiling ones (Ericson, Wollin and Wollin, 1954). In living populations, the left-coiling variety is also generally dominant, especially during the winter



TEXT-FIGURE 6

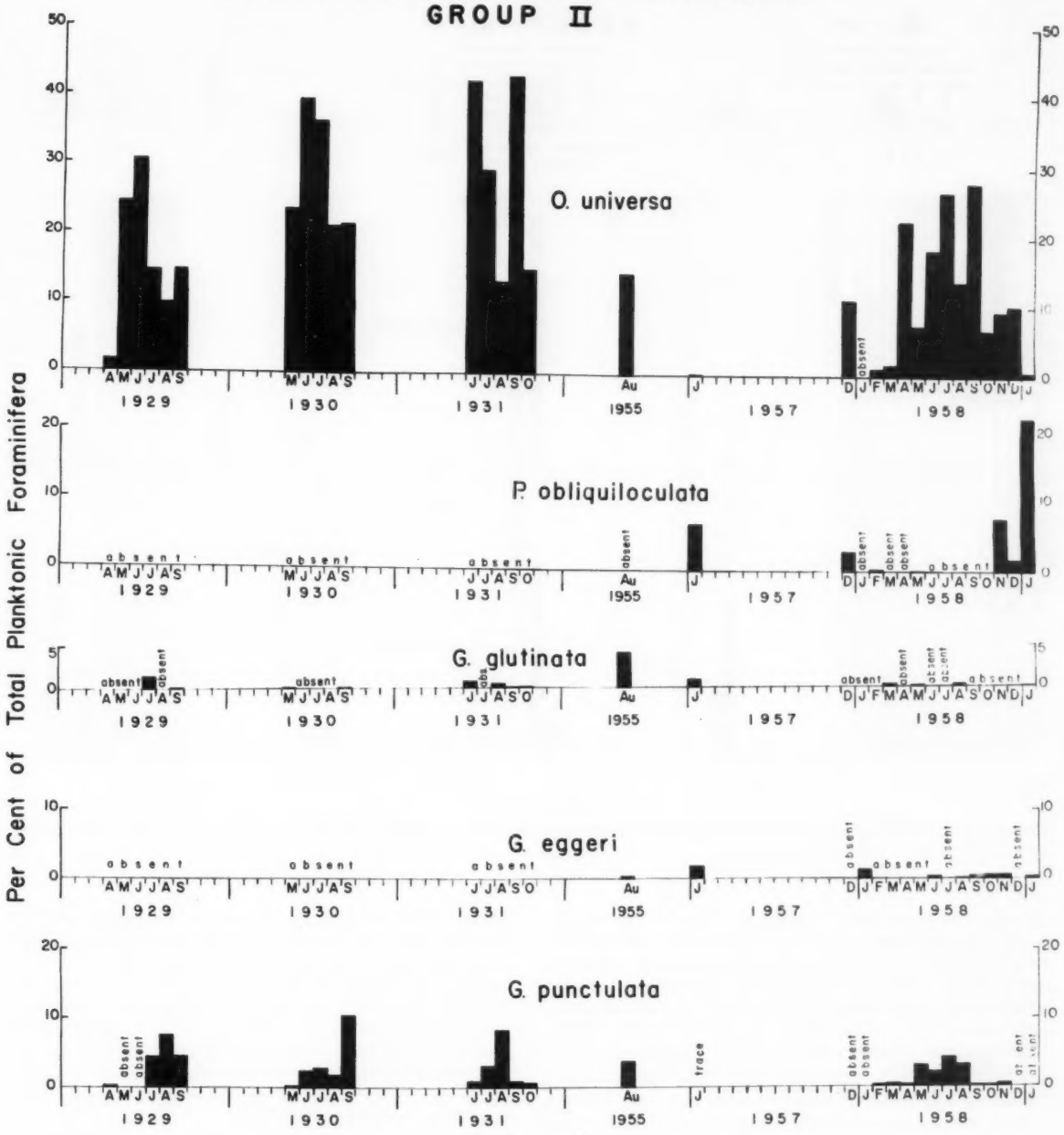
Relative abundance of planktonic foraminifera in Bermuda waters for certain months of 1929, 1930, 1931, 1955, 1957, 1958, and 1959.



TEXT-FIGURE 7

Relative abundance of planktonic foraminifera in Bermuda waters for certain months of 1929, 1930, 1931, 1955, 1957, 1958, and 1959.

months between January and April. The right-coiling variety appears to occur in more or less uniform frequency throughout the year, except between October and December when both varieties are rare or absent. When the percentage of left-coiling *G. truncatulinoides* to the total of left- and right-coiling individuals is determined (text-fig. 12b), it appears that, for the period under consideration, the left-coiling variety was dominant between April and July, 1929; between May and August, 1930; in June, September and October, 1931; and between January and June and from September to December, 1958. On the other hand, the right-coiling variety was dominant during August and September, 1929; September, 1930; July and August, 1931; and July and August, 1958. The continuity of collecting makes the 1958 samples significant; this series of samples suggests that during only two months of 1958 (July and August) the right-coiling type is proportionately more abundant than the left-coiling variety. It is not clear whether the brief dominance of right-coiling *G. truncatulinoides* during certain summer months is due to (a) the general sparsity of both varieties during the warmer



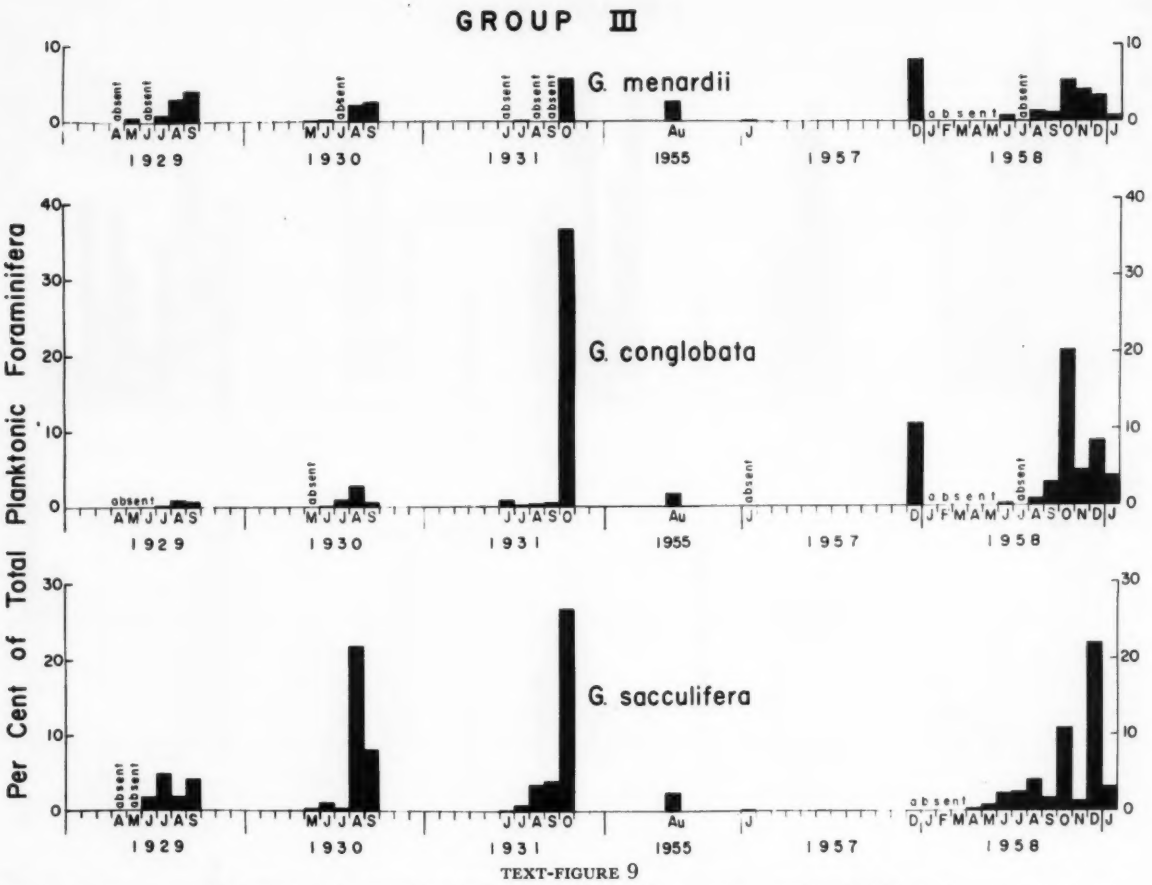
TEXT-FIGURE 8

Relative abundance of planktonic foraminifera in Bermuda waters for certain months of 1929, 1930, 1931, 1955, 1957, 1958, and 1959.

months, accompanied by a slightly greater survival rate of the right- over the left-coiling variety, or (b) an influx of waters carrying right-coiling individuals from their original domain in the slope waters of the North American continental shelf.

Hydrography

Bermuda is located in the northwestern section of the Sargasso Sea. Its position in the middle latitudes and the existence of several different water masses between New England and Bermuda have made the latter a favorable area for seasonal studies in physical and



TEXT-FIGURE 9

Relative abundance of planktonic foraminifera in Bermuda waters for certain months of 1929, 1930, 1931, 1955, 1957, 1958 and 1959.

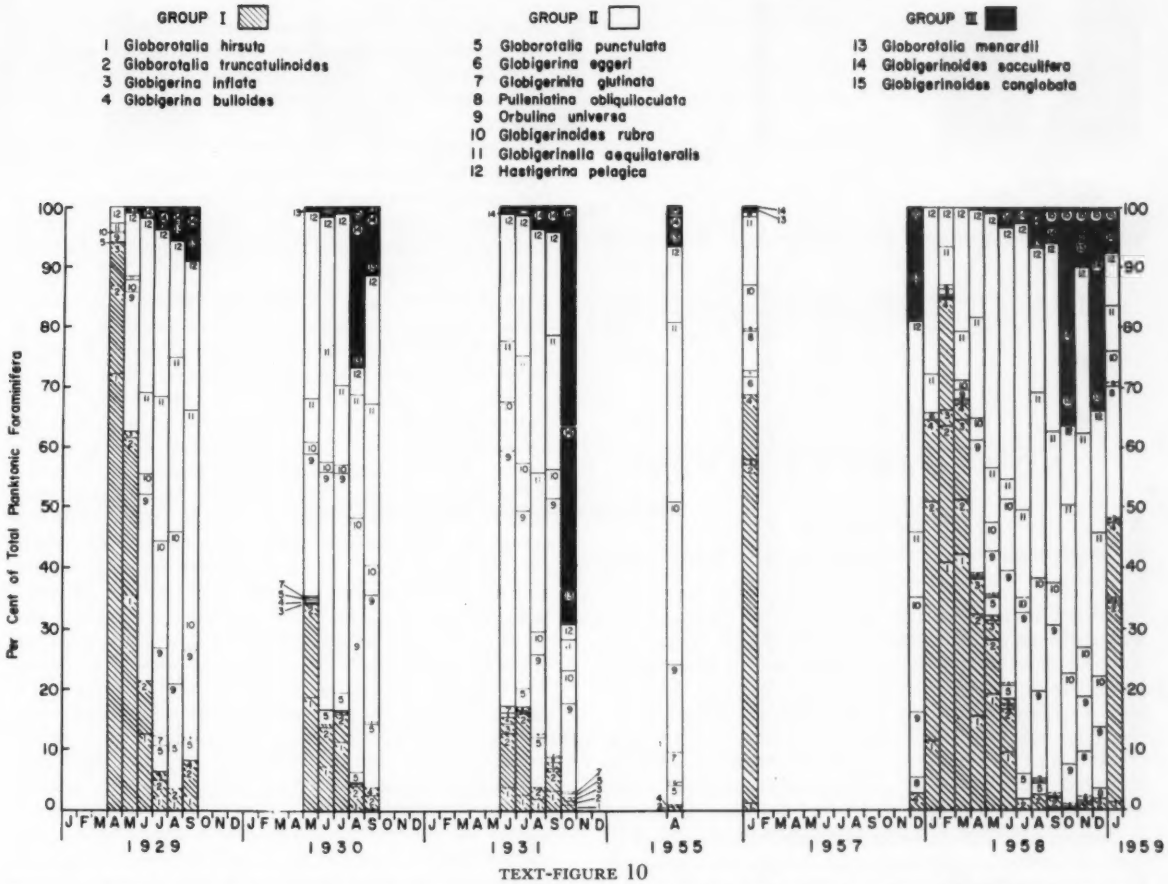
biological oceanography. It also serves as an excellent base of comparison with other regions of the North Atlantic. Much of our present knowledge of the hydrography of the western North Atlantic has been gathered by oceanographers of the Woods Hole Oceanographic Institution (e.g. Iselin, 1936; Fuglister, 1947, 1951, 1955; Fuglister and Worthington, 1951; Stommel, 1958; Worthington, 1959; Schroeder, Stommel, Menzel, Sutcliffe, 1959; Menzel and Ryther, 1960).

The Sargasso Sea is a central water mass in the North Atlantic, having relatively constant temperature and salinity values in the upper several hundred meters which differentiate it from other adjacent and underlying water masses. Its western and northern boundaries are sharply defined by the southern edge of the unusually strong set of fluctuating currents of the Gulf Stream System and the North Atlantic Current. Its eastern and southern boundaries are outlined by the Canaries Current and the North Equatorial Current.

In the vertical structure of the central Sargasso Sea Iselin (1936) and Stommel (1958) have distinguished three thermal zones: (a) a warm, upper layer between surface and 600 m. depth, having water temperatures of 17°C or higher; (b) an intermediate layer between approximately 600 and 1200 m. depth, where water temperatures rapidly decrease from 16° to 5°C, called the permanent or main thermocline; and (c) a cold, deep layer from 1200 m. to the ocean bottom with temperatures colder than 5° C.

For the present investigation, the warm, upper layer can be distinguished as the Sargasso Sea proper. It is lens-shaped, having a maximum thickness of 600 m. in the center and tapering to the surface towards its boundaries. In the northern Sargasso Sea and the Bermuda area, seasonal changes are pronounced within the upper 200 meters.

Between the seasonal and permanent thermoclines, there is an isothermal/isohaline body of water about 250 m. thick that is distributed over an extensive region



TEXT-FIGURE 10

Seasonal fluctuations in the species composition of planktonic foraminifera in Bermuda waters. Group I species are most abundant in winter and spring; Group II in summer; and Group III in late summer and fall.

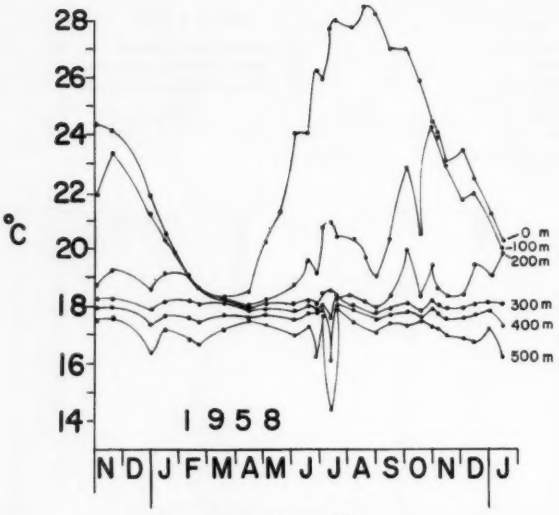
of the northwestern Sargasso Sea. This layer of water remains remarkably constant at a temperature of 17.9°C $\pm$ 0.3°C and salinity of 36.50‰ $\pm$ 0.10‰, and therefore, it has been termed the "Eighteen Degree Centigrade Water" by Schroeder *et al.* (1959) and Worthington (1959). It is formed each winter, generally towards the end of February, in the surface waters of the northern Sargasso Sea, between the Gulf Stream and Bermuda. As the surface waters here are cooled to a temperature of about 18°C, this isothermal/isohaline layer flows off southward at the 300-m. level and can be recognized distinctly as a rather thick layer above the permanent thermocline. To the north and west the Eighteen Degree Water is distinctly bounded by the Gulf Stream System, but its southern (about Lat. 20° N.) and eastern (about Long. 40° W.) limits are less well defined.

The southward submergence of Eighteen Degree Water from a region immediately south of the Gulf Stream in late February may serve as a mechanism for transportation of planktonic organisms to such regions as Bermuda. Worthington (personal communication) has estimated that this process may take 20 to 30 days. The vertical dimensions, the formative area in the northern Sargasso Sea and the southward penetration of Eighteen Degree Water are shown in text-figure 13.

The seasonal depth profiles in Bermuda waters of temperature, salinity, phosphate-phosphorus, chlorophyll *a*, and the seasonal variations in net primary production and zooplankton displacement volumes from January, 1958 through January, 1959 have been obtained by Menzel and Ryther (1960, and unpublished data) and are reproduced in text-figures 14–18. These observations have shown significant seasonal variations in the chemistry and hydrography of Bermuda waters.

DISCUSSION

When a correlation is sought between the foraminiferal distribution patterns and the ecological factors, it appears that those factors with seasonal cycles are likely to be responsible for the observed population trends. Since



TEXT-FIGURE 11

Seasonal change in water temperature in Bermuda waters.

variations in temperature, salinity, light transparency and nutrients of the waters are season-dependent, it is believed that they also are important in controlling phytoplankton and zooplankton abundances. Menzel and Ryther (1960) have shown seasonal variations in the plant nutrients (phosphate, nitrate, nitrite and silicate) in the euphotic zone of Bermuda waters, although these were not as pronounced as those variations found in more temperate and northern waters.

In late winter and early spring, maximum concentrations of nitrogen and phosphorus compounds appeared in near-surface waters due to vertical mixing of waters during the winter stirring and spring overturn. As a result a nearly isothermal/isohaline layer was developed in the upper 300 m. Between February and May temperatures were relatively low (between 18° and 20°C) and salinities relatively high (about 36.50‰) throughout the upper 300 meters.

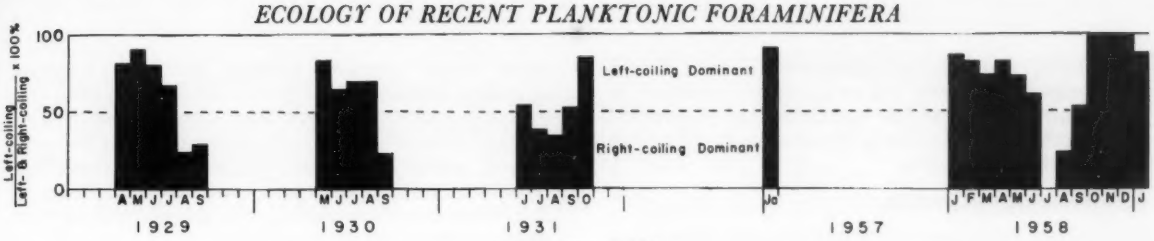
Menzel and Ryther (unpublished data) have observed that the appearance of high nutrient concentrations in the near-surface Bermuda waters resulted in the spring flowering of phytoplankton (chlorophyll concentrations up to 1.00 mg./m.^{3}). This maximum abundance of phytoplankton, in turn, provided a food supply for the zooplankton and directly preceded the zooplankton outburst with standing crops up to 0.2 ml./m.^{3}. The close relationship between phytoplankton and zooplankton productivities can be recognized from the immediate increase of the latter group following the maximum growth of the plant populations. As nutrient exhaustion terminated the phytoplankton flowering, there was further depletion of this group due to grazing by zooplankton. Gradually, the zooplankton also decreased because of lack of phytoplankton for food supply, as shown by the close coincidence in the reduction of both groups (text-fig. 18). Zooplankton standing crops were low and relatively constant throughout the year. Maximum abundances were observed in the spring of 1958 and of 1959, although in 1958 the spring maximum displacement volume exceeded that of 1959 by a factor of four.

The sequence of nutrient enrichment of the waters during the late winter and spring months, followed by the spring flowering of phytoplankton and maximum zooplankton abundances, also coincided approximately with peak abundances of the temperate species of planktonic foraminifera.

During summer and fall, thermal stratification of subsurface waters corresponded with low standing crops of phytoplankton (0.1 mg. of chlorophyll per m.^{3}) and of zooplankton (less than 0.03 ml./m.^{3}). This organic poverty was probably caused by the relatively low nutrient contents of the waters from June through October, when there was no effective stirring of the waters. Water temperatures varied from a maximum of 28°C at the surface, 20°C at 100 m., 18.5°C at 200 m., and 18.1°C at 300 meters in August, 1958. With increase in temperature there was an accompanying decrease in salinity. From mid-June through August and from September through mid-October of 1958 near-surface salinities were as low as 36.2‰ and 36.1‰, in contrast to average near-surface salinities between 36.3‰ to 36.5‰ for the remainder of the year. The decrease in salinities for one- or two-month periods during the summer appears to be a seasonal phenomenon. In summary, the increase in temperature but corresponding decrease in salinity, nutrients, phytoplankton and zooplankton standing crops during the warmer months can be correlated with the reduction of temperate species, the appearance and peak development of the subtropical species *G. sacculifer*, *G. conglobatus* and *G. menardii* and maximum concentrations of Group II species.

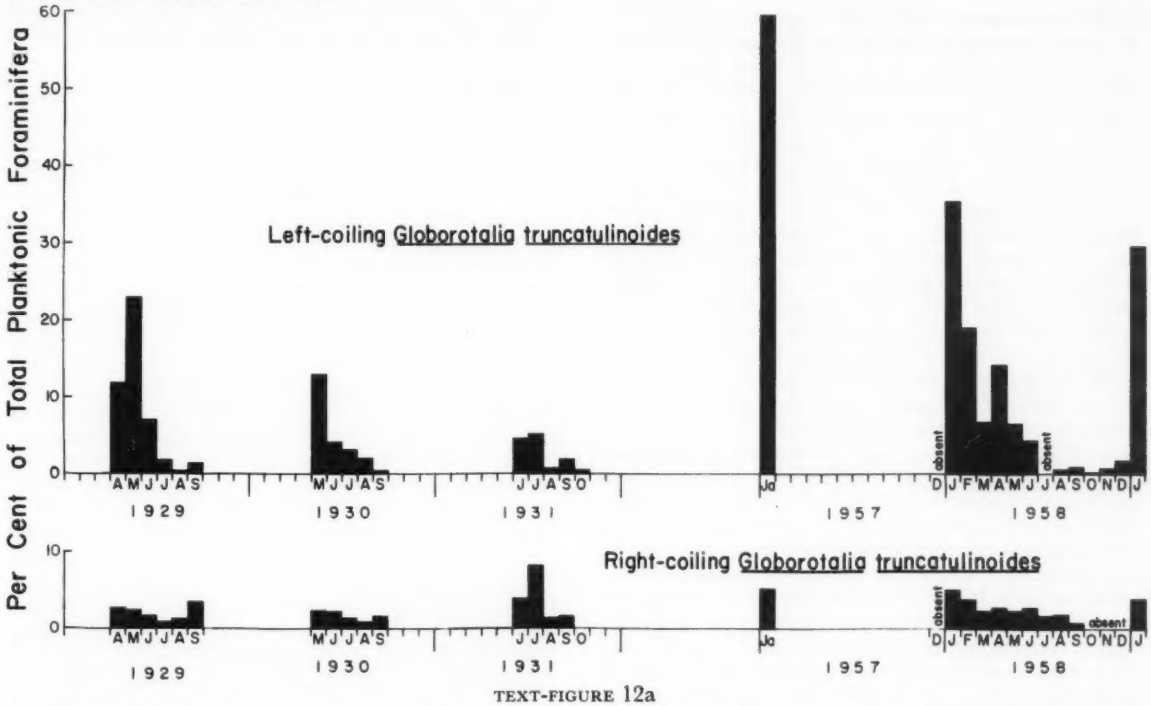
The occurrence of temperate species in the Bermuda region is somewhat puzzling. During the summer they are found predominantly north of the Gulf Stream System (Bé, 1959) and are practically absent in Bermuda waters. Yet during the winter months they make up the bulk of the foraminiferal populations in Bermuda waters. What is the origin of these temperate species?

Hela, Moore and Owre (1953) also noted seasonal changes in the surface water masses and in their plankton in the Bermuda area. They found that typical summer and winter species had widely different centers of geographic distribution and concluded that "Bermuda summer water comes from the North Equatorial Current, while the winter water comes from an eddy of the Gulf Stream approximately along the 30° parallel." However, there is one significant difference between the siphonophore and chaetognath distributions studies by Hela *et al.* and the foraminiferal distributions. In the present study, cold- and warm-tolerant foraminiferal species were observed in the winter and summer seasons, respectively. However, the colder chaetognath and siphonophore forms were found in the summer, and the warmer forms in the winter in the Bermuda area (H. B. Moore, personal communication).



TEXT-FIGURE 12b

Seasonal variations in the percentages of left-coiling to the total of left- and right-coiling specimens of *Globorotalia truncatulinoides* in Bermuda waters.



TEXT-FIGURE 12a

Seasonal variations in the relative abundance of left-coiling and right-coiling specimens of *Globorotalia truncatulinoides* in Bermuda waters.

There are two hypotheses that can explain the appearance of temperate species of planktonic foraminifera in Bermuda waters during the colder months: (1) they "migrate," as transported populations, southward during the winter from latitudes north of the Gulf Stream System; or (2) they are present as indigenous populations all-year round in Bermuda waters, but flourish in the winter and spring months, while they are rare and masked by other, more dominant species in the warmer months.

The first hypothesis requires transport of several hundred miles across the northeastward flowing Gulf Stream System. This is a difficult and perhaps impossible task if most of the temperate individuals need to come from the region north of the Gulf Stream. If they are present in large numbers within or just south of the Gulf Stream System, their southward transport might be aided by the convergence of Eighteen Degree Water (Worthington, 1959) in February which could bring them southward at the 300 m. level to locations such as Bermuda. However, the formation of Eighteen Degree Water during only a few days at the end of February and the beginning of March (Worthington, personal communication) precludes it as a mechanism of transportation for the temperate foraminifera, because large numbers of them are already present in Bermuda waters in January.

It appears, therefore, that the second hypothesis is a more likely explanation, i.e., that the temperate species are present in Bermuda waters throughout the year, but that they appear in enormous numbers during the winter and spring months only. Thus, their occurrence

is probably not due to transportation by different water masses, but rather due to significant variations in species abundances which themselves are dependent upon regular seasonal cycles in the chemistry and hydrography of the local waters.

PALEOECOLOGIC IMPLICATIONS

The seasonal alternation of temperate and subtropical species in Bermuda waters has a direct influence upon the species composition of tests accumulating on the ocean floor beneath. It is apparent that the occurrence of planktonic species with unlike ecologic tolerances in the same geographic locality but during different seasons must be reflected as a mixed assemblage in the sediments. Thus, it is not necessarily valid to infer from empty tests of bottom samples that the planktonic species originally have lived simultaneously in the overlying waters, as Emiliani (1954) has implied. He assumed that the different species from the same sediment sample each occupied its own specific depth habitat, as deduced from their temperature values based on oxygen isotope ratios of the foraminiferal tests. In the light of the present study, his data may be interpreted in another way — i. e., the variations of temperature values for the foraminiferal species were not necessarily due to their adaptation to different depth levels, but they were dependent upon temperature conditions within the euphotic zone during the *season* in which test secretion took place. The seasonal alternations of cold- and warm-tolerant species at the same oceanic location, as those observed in present-day Bermuda waters, point out the possibility that species with unlike temperature tolerances can occur together in the same sediment samples. During their lives, such species may have been adapted to surface temperature differences (between the warmest and coldest months) with magnitudes of eight degrees centigrade in the Bermuda region, of three degrees in the equatorial Atlantic, and of fourteen degrees in the Gulf Stream System north of Bermuda. These facts should be considered when temperature values are assigned on the basis of proportions of tests belonging to cold- and warm-tolerant species in bottom sediments.

FAUNAL BOUNDARY

In order that transitions from temperate to subtropical conditions, and *vice versa*, in Bermuda waters can be more firmly established on a faunal basis, it is here proposed that *Globigerina inflata* and *Globigerinoides sacculifer* be selected as representative species of Group I and Group III, respectively. Both species are abundant and widely distributed in their respective geographic provinces and are easily identifiable. A ratio between these species serves as an index of the degree of mixing of temperate and subtropical species. Presence of the temperate-subtropical faunal boundary may be inferred whenever and wherever there is an equal ratio of individuals belonging to these species.

Seasonal variations of the "*inflata*-to-*sacculifer*" ratios, converted to percentages of *G. inflata* to the total of *G. inflata* and *G. sacculifer*, indicate that such a faunal boundary appears twice a year in Bermuda, waters, i.e., during June-July and December-January (text-fig. 19). In 1958–1959 approximately seven months of the year showed subtropical conditions, while the remaining months of the year were temperate. The occurrence of this faunal boundary coincides in general with surface-water temperatures of about 23° C.

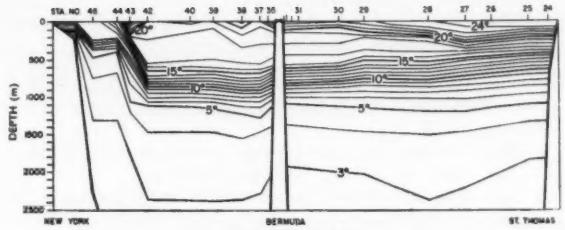
If these observations are representative of conditions over an extensive region around Bermuda, the present method may become applicable in delineating seasonal shifts of the temperate-subtropical boundary over a broad area of the North Atlantic.

SUMMARY

The present study shows significant seasonal variations in the species composition and standing crops of planktonic foraminiferal populations in the northern Sargasso Sea off Bermuda. Considerable numbers of four temperate species, *Globigerina bulloides*, *G. inflata*, *Globorotalia truncatulinoides* and *G. hirsuta*, are present from January to May in the upper several hundred meters of relatively cold water. These species are absent or rare and are replaced by the subtropical species, *Globigerinoides sacculifer*, *G. conglobatus* and *Globorotalia menardii* from June to December. The alternating appearances of the two groups occur so regularly that it is possible to determine the approximate month of the year from the foraminiferal species composition in a plankton sample. Their successive replacements are believed to be dependent upon regular seasonal cycles in the chemistry and hydrography of the local waters, rather than due to transportation of the foraminiferal species by different water masses. A third group of species with less well-defined seasonal maxima consists of *Orbulina universa*, *Hastigerina pelagica*, *Globigerinella aequilateralis*, *Globigerinoides ruber*, *Pulleniatina obliquiloculata*, *Globigerinita glutinata*, *Globorotalia punctulata*, and *Globigerina eggeri*.

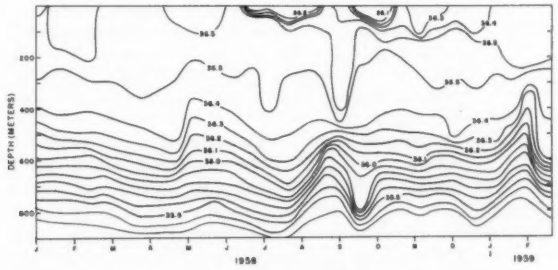
The occurrence of temperate species coincides approximately with high nutrient concentrations, peak phytoplankton and zooplankton abundances, relatively low temperatures and high salinities of the waters. On the other hand, the subtropical species are predominant during the summer and fall when the waters have low concentrations of nutrients, phytoplankton and zooplankton; and relatively high temperatures and low salinities.

From limited field observations made in January, 1957, it appeared that planktonic foraminifera were most abundant in the euphotic zone. No species stratification was evident, which might be attributed to the nearly isothermal waters during winter. With increasing depth, the color of the protoplasm of several species was generally whitish in contrast to a more greenish color in specimens of the same species caught in near-surface waters. The tests of individuals living below the euphotic zone were also generally thicker and more opaque than of those living near the surface, suggesting that test secretion continued below the euphotic zone.



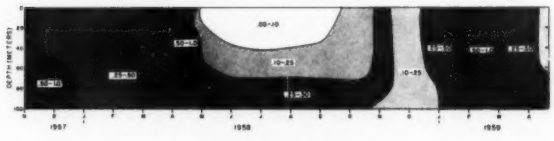
TEXT-FIGURE 13

Eighteen Degree Water, roughly between the 17° and 19°C isotherms, is shown here as a relatively thick layer above the permanent thermocline. Note its proximity to the surface south of the Gulf Stream (Stations 42–44) and its gradual diminution towards St. Thomas. *Challenger* sections, 1873: New York to Bermuda, Bermuda to St. Thomas. Reproduced from Wyville-Thomson (1877) by Worthington (1959).



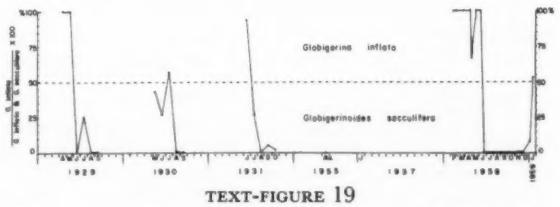
TEXT-FIGURE 15

The seasonal depth profile of salinity (‰) of Bermuda waters (after Menzel and Ryther, 1960).



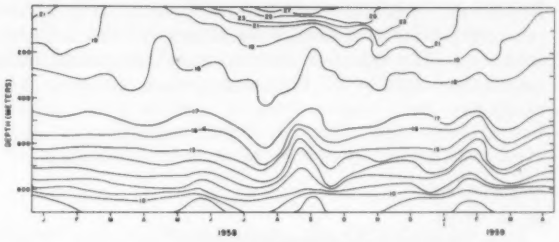
TEXT-FIGURE 17

The seasonal depth profile of chlorophyll *a* (mg/m³) in Bermuda waters (after Menzel and Ryther, 1960).



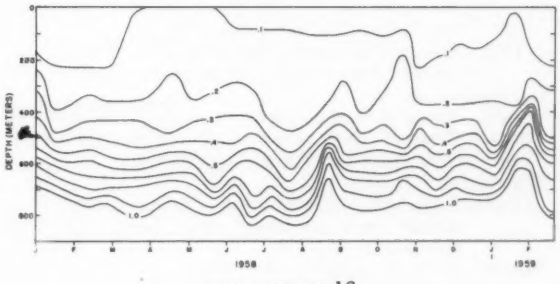
TEXT-FIGURE 19

Seasonal variations in the percentages of *Globigerina inflata* to the total of *G. inflata* and *Globigerinoides sacculifer* in Bermuda waters. In 1958–1959 temperate *G. inflata* predominated from January to early June, while subtropical *G. sacculifer* predominated from mid-June to January.



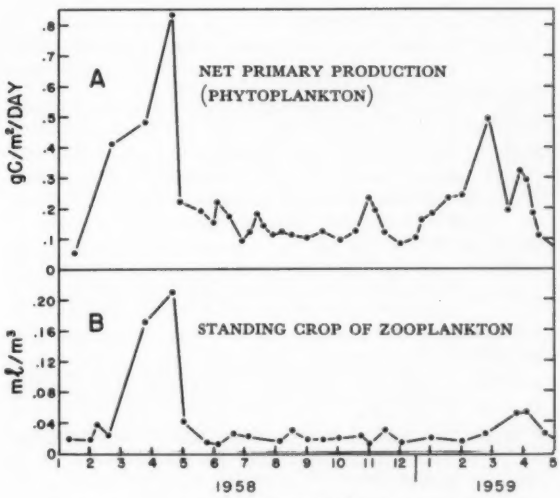
TEXT-FIGURE 14

The seasonal depth profile of temperature (°C) of Bermuda waters (after Menzel and Ryther, 1960).



TEXT-FIGURE 16

The seasonal depth profile of phosphate-phosphorus (μg A/L) in Bermuda waters (after Menzel and Ryther, 1960).



TEXT-FIGURE 18

Seasonal variations in net primary production (phytoplankton) (A) and standing crop of zooplankton in terms of displacement volume (B) in Bermuda waters (after Menzel and Ryther, unpublished data).

Results of the present investigation have bearing upon the interpretation of fossil assemblages in local bottom sediments. The seasonal alternations of temperate and subtropical species in Bermuda waters indicate the possibility that empty tests of species with unlike temperature and other ecologic requirements can eventually occur together in the same bottom sediment.

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ABSTRACT: *Individuals of the marine ostracode* Hemicythere conradi *Howe and McGuirt were acclimated in the laboratory at a salinity of 30 parts per thousand and water temperatures of 20–26° C. They were able to survive salinities from 6 to 65 parts per thousand and water temperatures from 6° to 36° C. Individuals of this species also exhibited a positive response to light and preferred silty sand to coarser oolitic sand when given free choice in laboratory experiments. The results are discussed in relation to the distribution of the species in the field.*

Some environmental boundaries of a marine ostracode

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INTRODUCTION

The use of fossil ostracodes to determine the environmental conditions which existed during the time of sediment deposition is limited because of lack of information concerning environmental factors influencing ostracode distribution. Knowledge of the environments in which ostracodes are living in today's seas is useful in that this information can be projected backward in time in order to estimate the environmental conditions present when these same species are found in Tertiary sediments. Ecological field studies of Recent ostracodes include those of Swain (1955), Puri and Hulings (1957), in the Gulf of Mexico area; Hartmann (1959) in South America; Kornicker (1958) in the Bahamas; and Benson (1959) in California.

Ecological studies restricted to field observations provide only limited information because of the difficulty of determining the influence of any part of the environment on species distribution. A similarity between the distribution of a species and one environmental factor is often assumed to indicate that the species is being controlled by that environmental factor. Unfortunately, the similarity may be coincidental, or may be due to some other environmental factor not measured. The field worker is usually limited to measuring only a few environmental factors and often is able to collect data only part of the year.

When one environmental factor can be varied while others are held constant, significant information may be obtained concerning the affect of a specific environmental factor on ostracodes in the laboratory. In the present paper, results are presented of experiments designed to determine the affect of temperature, salinity, sediment type, and light on *Hemicythere conradi* Howe and McGuirt, a marine ostracode abundant in the Laguna Madre and adjacent bays of Texas. The results, relative to the distribution of the species in the field (text-fig. 1), are discussed.

ACKNOWLEDGMENT

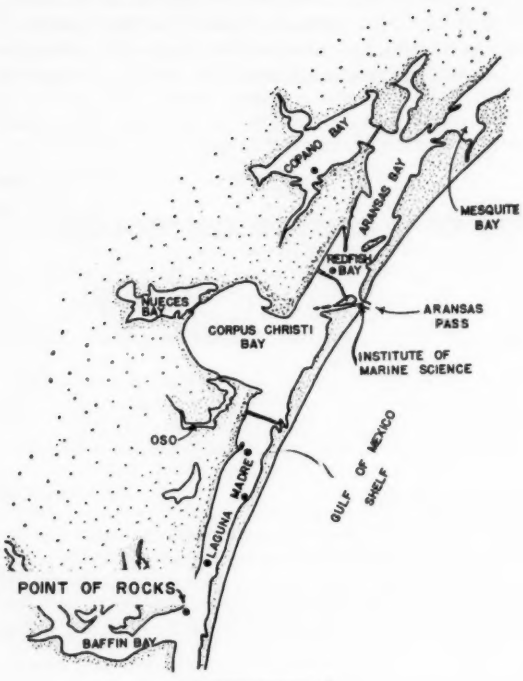
Dr. W. N. McFarland was consulted concerning techniques for determining temperature and salinity tolerance; he also read the manuscript critically. Dr. C. H. Oppenheimer also criticized the manuscript. The work was supported by National Science Foundation, grant no. 5473.

TEMPERATURE TOLERANCE

Water temperatures at twelve stations along the upper Laguna Madre ranged from 4° to 35° C. during the years 1951–1955 (Simmons, 1957). Water temperatures of 2–35° C. were obtained in the upper Laguna Madre during the period from April 1, 1958 to June 14, 1959, by Simmons (1960, written communication). Temperatures below about 9° C. probably seldom persist for more than 2–3 days.

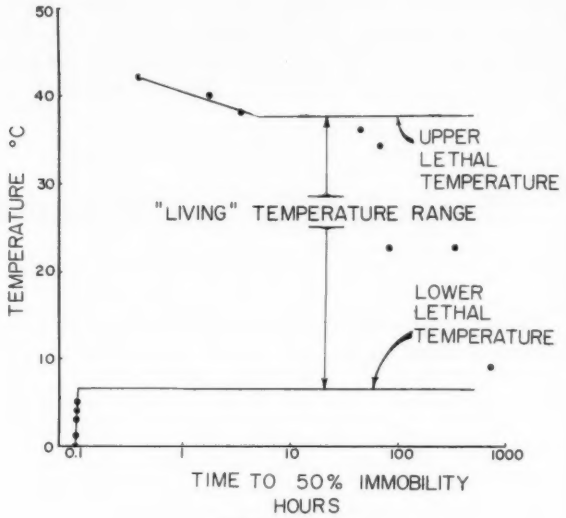
Living individuals of *H. conradi* were found in samples collected monthly in the upper Laguna Madre, Aransas Bay, and Copano Bay during 1958–1959. Water temperatures at the time of collection varied from 10° to 34° C.; however, temperatures obtained in-between sampling indicate the annual temperature range of waters in which *H. conradi* was collected to be 2° to 35° C. *H. conradi* was most abundant during the summer months and was relatively scarce during winter months.

The procedure used for determining the temperature tolerance of *H. conradi* in the laboratory is, briefly, as follows. Ostracodes collected in the upper Laguna Madre were held for a 5-day equilibration period in an aquarium containing water having a salinity of 33 parts per thousand and a water temperature of 20° to 26° C. Ten ostracodes were removed from the aquarium and placed in a culture dish containing water at the experimental temperature. The culture dish was then placed in an incubator in which the temperature could be controlled to $\pm$ $^1/_2$° C. The ostracodes were observed periodically and the time each ostracode became



TEXT-FIGURE 1

Location map showing sample stations.



TEXT-FIGURE 2

Temperature tolerance of *Hemicythere conradi* Howe and McGuirt. Each point represents the time 50 percent of the individuals in each experiment became motionless and stayed motionless until death. Ostracodes were first acclimated for a minimum of 5 days at a temperature of 20–26° C. and a salinity of 33 parts per thousand.

motionless noted. It was necessary to use the time at which the specimens became motionless rather than the time of death because of the difficulty in determining the precise time of death. This technique is considered valid because an inactive animal in nature will eventually die of starvation. Tests were made at temperatures between 0° and 42° C. The time at which 50 percent of the specimens in each test became motionless was then plotted graphically against test temperatures (text-fig. 2).

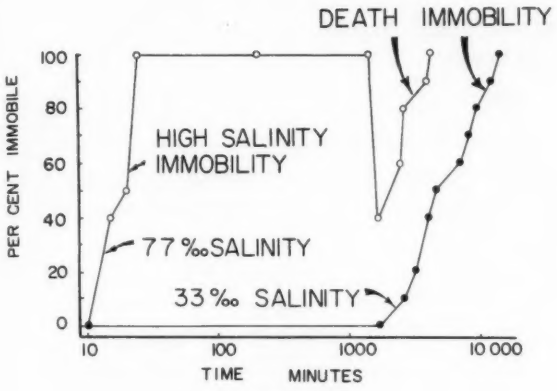
Text-figure 2 shows that below approximately 6° C. and above approximately 36° C. the time to 50 percent immobility was markedly shorter than at temperatures between these limits. The low temperature tolerance limit was also determined by lowering the temperature of water in a culture dish while observing the behavior of ten specimens in the dish; 50 percent immobility occurred at approximately 6° C., the same temperature as estimated from text-figure 2. The tolerance limits, as determined in the laboratory, are quite close to the maximum and minimum temperatures that normally prevail in the waters from which they were collected; however, the minimum tolerance temperature is above the water temperature during unusually cold weather. When the water temperature in the natural environment drops below 6° C., it is likely that *H. conradi* becomes inactive.

Additional laboratory experiments indicate that *H. conradi* is able to survive the short periods of unusually cold water to which they are occasionally exposed in the natural environment. Ten specimens kept for 24 hours at 0° C. and ten specimens kept for 96 hours at 3° C. were alive and vigorous after they were returned to 21° C. Ten specimens kept at –10° C. for one hour (ice formed in the 33 parts per thousand water) became active when brought back to room temperature of 21° C.

In order to determine the limits of the tolerance zone more accurately it would be necessary to repeat these tests after acclimatizing the ostracodes at other temperatures. Salinity may also have an effect on temperature tolerance. In the present tests, mature ostracodes and late instars were used; the tolerance range of other instars is probably different (Runnström, 1928). The reader is referred to Bliss (1937), Fry (1957), and Andrewartha and Birch (1954, chap. 6) for further discussion of methods and the effects of temperature on animals.

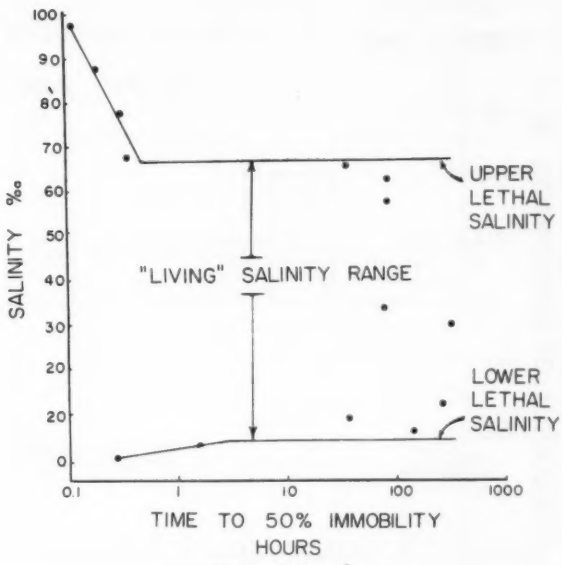
SALINITY TOLERANCE

Specimens of *H. conradi* were collected alive during 1958–1959 from water having salinities ranging from 8 to 51 parts per thousand at the time of collecting. During the years 1952–1955, when there was little rainfall, salinities above 65 parts per thousand were



TEXT-FIGURE 3

Time- "mortality" curves for *Hemicythere conradi* Howe and McGuirt at salinities of 77 and 33 parts per thousand. Temperature during acclimatization period and experiments remained between 20–26° C.



TEXT-FIGURE 4

Salinity tolerance of *Hemicythere conradi* Howe and McGuirt. Each datum point represents the time 50 percent of the individuals became motionless and stayed motionless until death. Ostracodes were first acclimated for a minimum of 5 days at a salinity of 33 parts per thousand. Temperature during acclimatization and experiments remained between 20–26° C.

recorded in the Laguna Madre (Simmons, 1957). Hedgpeth (1953) indicates that during the years 1946–1948 salinities above 70 parts per thousand were common in the Laguna Madre. *H. conradi* was scarce at sampling stations in Copano Bay, where salinities as low as 9 parts per thousand were encountered, and at the two southernmost stations in the Laguna Madre, where salinities of 51 parts per thousand were recorded (text-fig. 1).

The procedure used for determining the salinity tolerance of *H. conradi* in the laboratory was essentially the same as that for temperature, except that specimens were subjected to waters having different salinities rather than different temperatures.

Specimens became inactive quite rapidly at a salinity of 77 parts per thousand but resumed activity shortly before death (text-fig. 3). The reactivation before death is considered to be a physiological response caused by imminent death rather than to acclimatization to the high salinity. The basis for this conclusion is that in all high salinity experiments the ostracodes became reactivated at approximately the same time, and because the time of reactivation coincided with the time at which specimens in the control experiment (at a salinity of 33 parts per thousand) began to die.

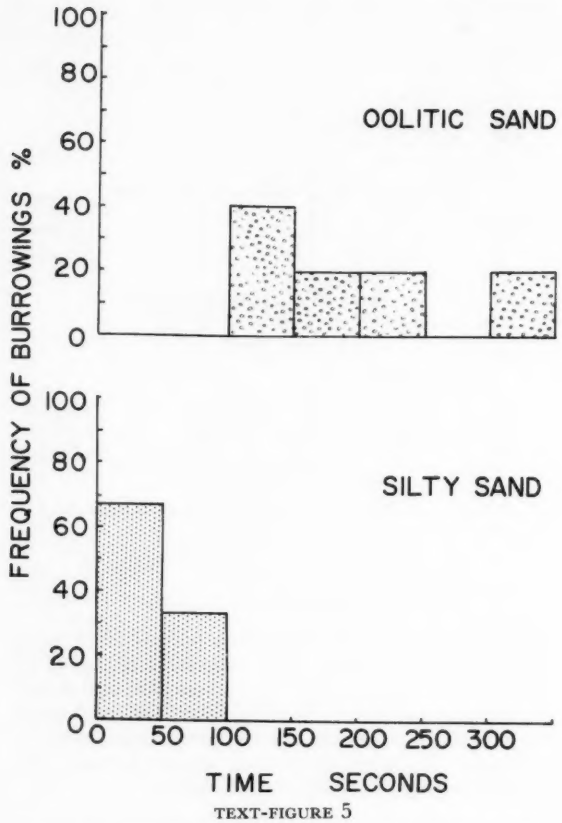
The time at which 50 percent of the specimens became motionless plotted graphically against the test salinity showed the upper salinity tolerance limit of *H. conradi* to be approximately 65 parts per thousand and the lower tolerance limit approximately 6 parts per thousand (text-fig. 4). The salinity ranges in which the species was collected in the field are within the tolerance limits obtained in the laboratory. The laboratory data suggest that in years of little rainfall when salinities in the Laguna Madre rise above 65 parts per thousand, *H. conradi* cannot survive. This suggests that the relative abundance of this species in sediment cores from the Laguna Madre might be used as an indication of climate at time of deposition.

In order to define more accurately the salinity tolerance limits, it would be necessary to determine the effect of acclimatizing the ostracodes at other salinities, and also the tolerance limits of earlier instars.

EFFECT OF SUBSTRATE

Ecological studies of marine ostracodes indicate that substrate plays a major role in determining ostracode distribution (Benson, 1959). Kornicker (1957) showed experimentally that two myodocopid ostracodes preferred to burrow into poorly-sorted bioclastic sand rather than into well-sorted oolite and attributed this to the ostracodes having physical difficulties in burrowing into well-sorted sand.

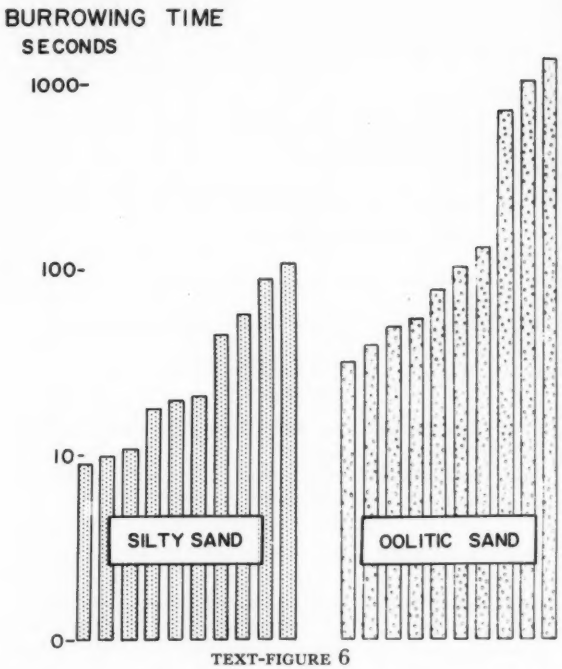
Previous to experiments with *H. conradi*, the writers observed that a specimen of *Sarsiella zostericola* Cushman? collected in the Laguna Madre burrowed readily into



TEXT-FIGURE 5

Burrowing speed of *Sarsiella zostericola* Cushman? in oolitic sand and silty sand. The histogram for oolitic sand represents 9 tests and the histogram for silty sand 5 tests; the silty sand tests were performed between two series consisting of 5 and 4 tests each with oolitic sand. The oolitic sand was obtained from the Point of Rocks area of the Laguna Madre; the silty sand was obtained from the upper part of the Laguna Madre where the specimen of *Sarsiella* was collected.

silty sand of the upper Laguna Madre where the ostracode was collected, but seemed to burrow with difficulty into a well-sorted sand, containing oolites, from the Point of Rocks area of the Laguna Madre. By recording the time for the specimen of *S. zostericola*? to burrow, it was possible to show graphically that the specimen took longer to burrow into the oolitic sand than it did to burrow into the silty sand (text-fig. 5). From observing the specimen at work it is the opinion of the writers that the specimen had physical difficulty in displacing the particles when trying to force its carapace into the oolitic sand, whereas, it had little difficulty in forcing its body into the silty sand. One might compare this with a dog or gopher having more difficulty digging a hole in gravel than in sand.

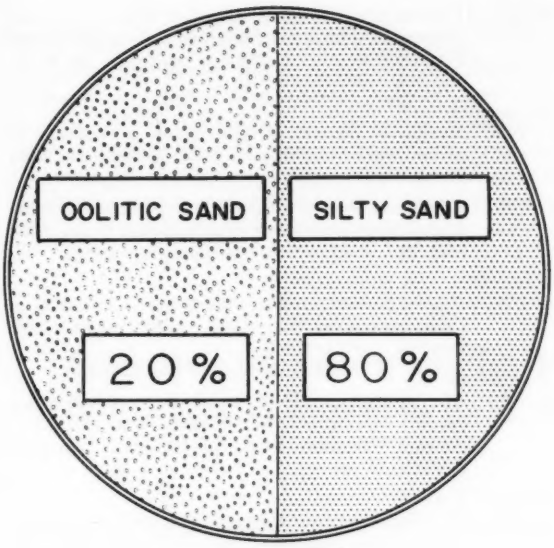


TEXT-FIGURE 6

Burrowing speed of *Hemicythere conradi* Howe and McGuirt on silty sand and oolitic sand. Each bar represents the time in seconds for one specimen to burrow into the sand. Twenty individuals were used in the experiments. Oolitic sand was obtained at the Point of Rocks area of the Laguna Madre; silty sand was obtained from the upper part of the Laguna Madre where the ostracodes were collected.

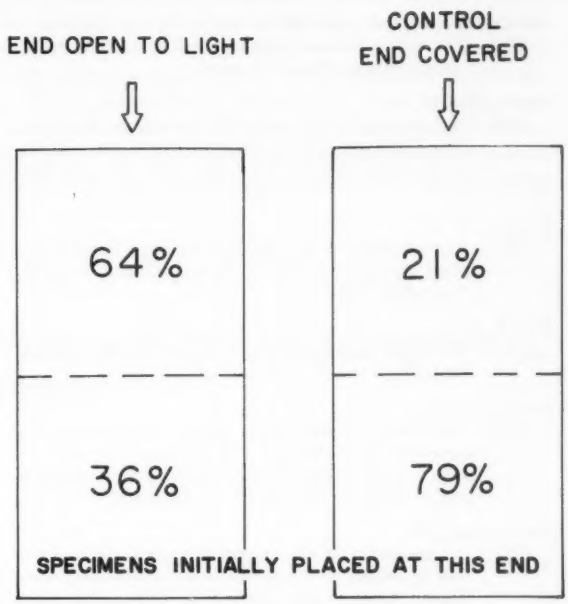
The experiment was repeated with twenty specimens of *H. conradi*. This species also burrowed more rapidly into the silty sand than into the oolitic sand (text-fig. 6). During the observation period, specimens of *H. conradi* weaved in and out of the sediment, spending more time in the sediment than out. This was in marked contrast with *S. zostericola*?, which usually stayed under the sediment for a considerable time after burrowing.

H. conradi apparently prefers silty sand to oolitic sand. This was demonstrated in experiments in which specimens were placed in a culture dish, 45 mm. in diameter, having silty sand in one half and oolitic sand in the other. Eighty percent (range 60–100 percent) of the ostracodes were found on the side with the silty sand, at the end of 18 hours (text-fig. 7). In view of the greater ease with which the specimens were able to burrow into the silty sand, the authors believe that the physical difference between sediments contributed to more specimens being found in the silty sand.



TEXT-FIGURE 7

Distribution of *Hemicythere conradi* Howe and McGuirt in oolitic sand and silty sand at the end of 18 hours. Tests were repeated 7 times using ten different specimens in each test. Range of values in the silty sand was 60 to 100 percent.



TEXT-FIGURE 8

Behavior of *Hemicythere conradi* Howe and McGuirt to wards light. Plastic boxes having the following dimensions were used in this experiment: length 45 mm. width 22 mm., height 20 mm. Five plastic boxes were covered with black tape except for one end, which was left open to permit the entrance of light. Four boxes used as controls were completely covered with the black tape. The 9 boxes were then placed side by side with the uncovered ends of the 5 test boxes about one foot from a desk lamp. Ten ostracodes were placed in the end of each box away from the light.

LIGHT RESPONSE

Kesling (1951) reviews the few experiments that have been performed to determine the effect of light on fresh-water ostracodes. Some species of fresh-water ostracodes are attracted to light whereas others are repelled. Kesling (1951) found that specimens of *Cypridopsis vidua* congregated in the unlighted area of a dish away from the light source, but were attracted to light after being held in the dark for an hour. Kornicker (1958) tested the response to light of several species of Myodocopa and found them to be attracted by light.

The effect of light on *H. conradi* was determined by placing specimens in 5 small rectangular plastic boxes and then exposing one end to a light source. Sixty-four percent (range 50–70 percent) of the specimens were found in the lighted ends of the boxes after 18 hours. Only 21 percent (range 0–40 percent) were found at the same end of 4 boxes used as controls (text-fig. 8). In the field, *H. conradi* was more abundant in shallow water than in deep water. It is possible that ostracode abundance is partly light-controlled.

CONCLUSIONS

1) Laboratory experiments in which various environmental conditions can be controlled may be useful in estimating the influence of a single environmental factor on the distribution of ostracodes in the natural environment.

2) Adults and late instars of the marine ostracode *H. conradi*, acclimated at 20–26° C. and 33 parts per thousand salinity for a minimum of 5 days, have a temperature range of 6° to 36° C., and a salinity range of 6 to 65 parts per thousand within which they are active.

3) At temperatures below 6° C., which occur periodically in their natural environment, specimens of *H. conradi* probably become motionless, but, because the low temperatures seldom persist for more than 2–3 days, the species may survive.

4) Although specimens of *H. conradi* are able to live in the upper Laguna Madre during wet years, they probably cannot survive dry years when the salinity rises above 65 parts per thousand.

5) Individuals of the species are attracted to light, and seem to prefer silty sand to coarser oolitic sand.

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ABSTRACT: *The following study is based on two samples of the Marianna limestone (Oligocene), from Little Stave Creek, Clarke County, Alabama. One sample is from the Limestone member and the other from the Mint Spring member. The entire foraminiferal population was studied in order to establish the relationship of the microforaminifera to the other foraminifera present in each sample. Measurements made on series of foraminifera ranging in size from 60 to 800 microns indicate the lack of a natural size boundary for the microforaminifera group. Identifications of microforaminifera, where possible, were based on comparisons with foraminifera of larger size. Most microforaminifera are believed to be megalospheric forms. Some microforaminifera are not sufficiently differentiated in coiling or distinctive in test character, to permit identification with established genera or species. The lithology and microfossil assemblage of the two samples suggest deposition of the Marianna limestone in clear, calm, lower-neritic waters.*

Microforaminifera of the Marianna limestone (Oligocene), from Little Stave Creek, Alabama

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INTRODUCTION

Although foraminifera are the most extensively studied group of microfossils, comparatively little is known about the smallest foraminifera, called "microforaminifera." The term microforaminifera was coined in 1952 by Wilson and Hoffmeister for a distinct size group, and not a natural taxon of foraminifera. Wilson and Hoffmeister apparently were the first to record these tiny forms from fossil and recent sediments, having found them in their spore and pollen macerations. They record these forms as follows (1952, p. 26): "During the course of microfossil studies of deep wells and Recent sediments, many minute foraminifera have been encountered in the residues of hydrochloric and hydrofluoric acid preparations. These foraminifera differ from those usually used in well correlation and age determination in that they are extremely small, usually 30 to 150 microns in length, and that they have tests that are not destroyed by either hydrochloric or hydrofluoric acids. Probably the most significant feature of the fossils is their association with other minute structures, particularly with spores and pollen."... "The fossils appear to be mostly tests belonging to the megalospheric generation of many existing foraminifera genera. However, a large number of individuals do not have the characteristic large proloculum and may represent genera of foraminifera not yet described. For lack of a better understanding at the present time, the writers, in their work, are referring to these interesting fossils as 'microforaminifera.' Tests of the organisms have been found in shales as old as the Cretaceous and in Recent sediments from the Gulf of Mexico, coast of New England, and the depths of the Atlantic ocean. To date, nearly every clastic marine sediment examined has contained remains of the tests."

Although Wilson and Hoffmeister originally described the microforaminifera on the basis of size, confusion has arisen in the use of the term. In many reports it has been used to designate foraminiferal tests and/or their chitinous chamber linings, both with and without size distinction. In other words, the term has been used to denote those foraminifera which have been isolated with other microfossils displaying similar resistance to the reagents used in the preparation of material. Variation in techniques of preparation may affect the isolation of different portions of foraminifera and microforaminifera and so controversy has arisen over the nature of the action of different reagents upon the foraminiferal test.

Microforaminifera reported from Cretaceous and younger sediments are usually noted in samples containing abundant tests of other foraminifera. This association should be expected, if the microforaminifera are megalospheric generations and are assignable to described genera.

In the following study of two samples of the Marianna limestone (Mint Spring and Limestone members), Little Stave Creek, Clarke County, Alabama, an attempt is made to: (1) evaluate the significance of the abundance of microforaminifera with relation to the other foraminifera present; (2) to determine possible

morphologic differences between microforaminifera and other foraminifera, and; (3) to establish, if possible, variations in size within individual genera.

This report reviews the history of the study of microforaminifera and the controversies involved, and outlines the preparation of material, and the statistical methods employed.

Most of the identifications of foraminifera in the coarse fraction were based on Bandy's (1949) work. For comparison, his identifications are listed in Table 1.

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HISTORICAL REVIEW

After Wilson and Hoffmeister (1952) published their first account of microforaminifera and the technique with which these forms could be separated, various explanations have been advanced to account for the survival of calcareous tests under acid treatment. As previously quoted, Wilson and Hoffmeister (1952) claimed that microforaminifera "have tests not destroyed by either hydrochloric or hydrofluoric acid," and illustrated a number of them and two fossils of uncertain affinity. In 1955, Hoffmeister further elaborated on the apparently acid-resistant remains of foraminifera by offering the following explanation (1955, p. 158): "Foraminifera have calcareous or siliceous shells, yet their remains are encountered in residues prepared with hydrofluoric acid which should ordinarily destroy these coverings. It is believed that some have not only calcareous or siliceous outer shells but also acid resistant inner coats which protect their individual chambers."

No mention was made of the conversion of calcium carbonate to calcium fluoride in the above explanation. In 1956, Grayson discussed the conversion of calcite to fluorite after he found fluoritized calcareous remains in a residue of a siliceous sample he had macerated for palynological work. He stated (1956, p. 71): "Upon examination, the debris was found to be composed of shell fragments. This was surprising because, until this time, it had been assumed that the hydrofluoric acid, being a halogen acid, would perform the same function as hydrochloric acid and would dissolve the calcium carbonate. Since hydrofluoric acid had not eliminated the calcareous matter, an attempt was made to dissolve it by treatment with hydrochloric acid. It was rather startling to find that upon treatment with hydrochloric acid no reaction occurred. The sample was washed with distilled water, and an X-ray analysis was made. The analysis showed that the shell fragments were no longer composed of calcium carbonate, but were now composed of calcium fluoride. The following equation shows the reaction that had occurred: $CaCO_3 + 2HF \rightarrow CaF_2 + CO_2 + H_2O$. This simple chemical equation is in itself not spectacular. Probably chemists have known about it for years, although it was not observed in a quick survey of chemical textbooks." Grayson then discusses the "microforaminifera" as described by Wilson and Hoffmeister in 1952, and says that "microforaminifera" are only present in his residues when the hydrochloric acid treatment follows the hydrofluoric acid. This, Grayson believes, is a result of fluoritization of the tests making them insoluble in hydrochloric acid He says (pp. 71–72): "Samples have been treated in our laboratory with hydrofluoric acid first, and in these 'microforaminifera' have been observed. The same samples pre-treated with hydrochloric acid reveal no trace of these organisms. There appears to be a conflict between Wilson and Hoffmeister's results and those of the author. This conflict is believed to be only apparent, however. In reality, the point of confusion may be a difference in interpretation of certain microfossils." Grayson believed two microfossils regarded as "microforaminifera" by Wilson and Hoffmeister (1952, text-figs. 22 and 23) to be multicellular fungal spores such as those found in the genus *Helminthosporium*. Grayson (p. 72, text-fig. 1) illustrates some of these which he extracted from Cretaceous sediments that had been treated with hydrochloric acid, prior to hydrofluoric acid.

In 1957, Otto Wetzel disagreed with Grayson's (1956) findings and the comments made on Wilson and Hoffmeister's work. He states (p. 61): "Both sets of figures, Wilson and Hoffmeister's text-figures 22 and 23 (1952) perhaps more clearly than some parts of Grayson's text-figure 1 (1956), show small round bodies arranged according to size in a short and sometimes incomplete spiral series. This structure is similar to that of the first-formed chambers of a number of foraminiferal species (Rotaliidae and others). The resistance of such membranous forms, which can be isolated from the enclosing sediments by acid treatment, is natural and requires no artificial conversion; it is a result of the fact that the inner coats of the individual chambers are composed of an organic chitin-like material. The occurrence of these spiral foraminiferal linings and of similar rectilinear chains of linings is not rare; they have been observed in various sediments and their residues by various authors since the days of Ehrenberg (1838, 1854). Eisenack (1954) recently published a brief bibliography of these microfossils. In the present note, I have assembled a few examples illustrating them (see also Wetzel, 1933*a*, *b*; 1948; 1951*a*, *b*). In addition to the membranous linings, there are other factors that may explain why these small chambers are recognizable in samples of sediments or their residues in spite of natural (not always complete) decalcification. One factor is pseudomorphous transformation of the microfossils, whose cavities or walls were previously filled diagenetically with sili-

ceous, pyritic or other mineral matter. This factor must also be remembered in considering the chemical composition of the 'microforaminifera' illustrated by Wilson and Hoffmeister (1952, text-figs. 1–20 or 21). Molecular replacement of matter during fossilization sometimes produces detailed reproductions of many different kinds of organisms (see my examples illustrating these foraminifera, as well as radiolaria and sponges). In 1953, I wrote (Wetzel, 1953*b*): 'All grades of transformation may be observed up to complete metasomatosis.'"

In the same journal, van Veen records recovering numerous inner linings of microforaminiferal tests isolated from highly calcareous Recent clays and silts. The author states (1957, p. 74): "The samples, highly calcareous clays and silts, were treated with hydrochloric acid to completion of reaction, prior to treatment with hydrofluoric acid, yet the tests still survived. This is at variance with the suggestion of Grayson (1956, pp. 71–72) that survival of the tests of calcareous microforaminifera is due to the conversion of the shells to fluorite during the initial treatment with hydrofluoric acid. If this assumption were valid, microforaminifera should not be present after treatment with hydrochloric acid prior to hydrofluoric acid. It appears, therefore, that, as Hoffmeister (1955) concluded, the survival of originally calcareous or arenaceous foraminifera is due to the presence of an acid-resistant (chitinous?) inner coat."

With regard to this controversy, the apparent misunderstandings seem to stem from incomplete experimentation or observation and, in reality, only a partial consideration of the issues involved being disputed.

Grayson (1956) observed that the calcareous portion of foraminiferal tests were actually converted to fluorite when immersed in hydrofluoric acid. This conversion is accepted as fact. As early as 1921, W. Wetzel reported the alteration of microfossils from calcium carbonate to calcium fluoride. This chemical reaction, however, does not have any bearing on, nor does it deny the existence of, an inner organic lining of a foraminiferal test.

Many of the calcareous foraminifera, both Recent and fossil, may be observed with the chitinous inner linings of their chambers intact. It is possible, in some cases, to remove these inner linings without chemical treatment; in other cases, outer calcareous coverings may be removed by acidizing in hydrochloric acid leaving inner linings intact as a fine film. A similar situation exists in some of the microforaminifera.

Concerning the discussion of the survival of foraminiferal tests after treatment with hydrochloric acid prior to hydrofluoric acid, laboratory studies made by the writers on several samples have given the following results. Some samples treated first with a 10% concentration of technical grade hydrochloric acid (approximately 37%) have in the residues remains of both larger foraminifera and the so-called microforaminifera. In these same samples, further acidizing with a fresh 10% solution of hydrochloric acid will frequently destroy all the calcareous forms, leaving a residue of a few chitinous chamber linings, generally disconnected, some single chambers and an occasional proloculus.

Treatment of the sample with hydrofluoric acid prior to hydrochloric acid, in all cases, yields a far greater number of foraminifera and microforaminifera. This chemical reaction does, however, have a corrosive effect on many of the forms, particularly when the reaction is violent. Sometimes the outer chambers in very porous tests will be destroyed.

It seems reasonable, therefore, to define microforaminifera on the basis of size distinction, as Wilson and Hoffmeister did in 1952, and not on forms remaining after acidizing with hydrochloric and hydrofluoric acids. Delimiting the size within which one might designate microforaminifera is an arbitrary choice, for as will be noted later in this study, there is apparently no natural boundary or break upon which such a distinction can be based.

METHOD OF SAMPLE PREPARATION

After several experimental runs using the short technique published by Wilson and Hoffmeister (1952) and several published methods for palynological preparation of sedimentary rocks, the following basic technique was applied to the Little Stave Creek samples.

1) Break consolidated sediments into fragments not over $^1/_4$" maximum dimension. Twenty to forty grams of each sample were prepared. Usually twenty to thirty grams of materials are required for extensive study, although five grams will generally yield a representative sampling of the microfossil assemblage.

2) Boil fragments for four hours in distilled water, with addition of about ten drops of Calgon solution for every 40 cc. of distilled water used. (Calgon is a commercial water softener, sodium hexametaphosphate. The solution consists of 6 grams of Calgon in 100 cc. of water.)

3) Pour off liquid and wash residue twice, allowing a settling time of at least 30 minutes between washings. Mix residue thoroughly and separate into two fractions; one fraction to be fluoritized, the other not.

4) Place one fraction in a copper or plastic container and under a fume hood, add three times its volume of cold, concentrated (technical grade, 52%) hydrofluoric acid, cover carefully and allow reaction to continue for 12 to 16 hours; stir occasionally. If reaction is not complete add small amounts of fresh acid and allow to stand for longer periods of time.

5. Pour off spent acid and wash residue at least three times.

6) Separate size fractions of both fluoritized and water-washed samples by wet sieving with screens; numbers 40 (420 micron opening), 60 (250 micron opening), 80 (177 micron opening), 200 (74 micron opening). Material retained on the 40 mesh, 60 mesh and 80 mesh is dried and examined for larger fossils.

7) Material retained on, and that which passes through, the 200 mesh screen is dehydrated twice with cellosolve or isopropyl alcohol. Material is then stored in 2 dram vials and examined in wet or permanent mounts. If stained specimens are desired, add a number of drops of safranin (0.1% in alcohol) solution to each residue.

8) Drop a small amount of residue in the center of a glass slide and allow alcohol to evaporate, but prevent sample from drying completely. Add 1 to 3 drops of diaphane and disperse material uniformly throughout mounting medium. Cover with warm no. 1 cover-glass and heat to bring diaphane to corner of cover slip. Gently warm slide until air bubbles expand and unite; the bubbles can then be removed from the mount with a slight release of pressure, by inserting a fine needle below the edge of the cover glass. Invert slide and warm at temperatures not greater than 45°C for a few hours. In a few days, circle the cover slip with a ringing cement for a permanent mount.

The above technique was applied to the Little Stave Creek samples. Modifications of this procedure would, of course, be made depending on the nature of the material to be prepared and the types of microfossils to be recovered.

LOCATION OF SECTION AND SAMPLE HORIZONS

The samples collected for this study are from exposures along the banks of Little Stave Creek, Clarke County, in southwest Alabama. Little Stave Creek flows S 10° W from its headwaters in sec. 21, T. 7 N., R. 2 E., to a region two to three miles north of Jackson, where it enters the Tombigbee River. Stream bank exposures, along the steep three mile course, reveal more than 400 feet of middle and upper Eocene and lower and middle Oligocene strata. This is one of the largest continuously outcropping sections in the Gulf Coast area.

The Guides to Southeastern Geology (1955, p. 457), published by the Geological Society of America, include Little Stave Creek as type locality no. 30 on stop 14 of the Alabama Field Trip.

Sample no. 1 was collected from the Marianna limestone, Limestone member, at a height of 55 feet above the Red Bluff—Mint Spring contact. The sampled horizon is 10 feet above Bandy's no. 66 sample horizon (1949, fig. 2) and 5 feet below his no. 67 sample. The material is a white, fine, massive, poorly cemented limestone with abundant microfossils.

Sample no. 2 was collected from the Marianna limestone, Mint Spring member, at a level of 10 feet above the Red Bluff—Mint Spring contact. It is 5 feet above Bandy's no. 64 sample and 15 feet below his no. 65 sample. Lithologically, it is similar to sample no. 1, but even more highly fossiliferous. A small percentage of the fossils are filled with glauconite and a few aggregates of microscopic euhedral pyrite crystals are present.

METHOD OF STUDY

Coarser fractions

To determine the variation in relative abundance of different species with fraction size, an arbitrary volume of material, 8cc. of $>$ 40 mesh fraction and 1cc. of both 40–60 and 60–80 mesh fractions, was picked of all specimens sufficiently well preserved to be identified to specific level. A greater amount of $>$ 40 mesh material was needed as this size range consisted dominantly of bryozoan fragments. Both fluoritized and nonfluoritized preparations were studied to determine the extent, if any, to which the hydrofluoric acid had selectively destroyed the arenaceous forms.

Specimens to be compared in size with those of the finer fractions were measured at 112.5 diameters magnification with a calibrated ocular micrometer, accurate to 0.025 mm. Representative specimens of common planispirally and trochospirally coiled foraminifera were picked from the fluoritized 60–80 mesh fraction and mounted in diaphane for comparison with the foraminifera of finer fractions (Upshaw, Todd and Allen, 1957).

Finer fractions

Approximately eight permanent diaphane mounts were prepared of each of the fractionated finer residues. Glycerine was used for supplementary, temporary mounts. These were examined with a binocular microscope at magnifications of 150×, 300×, and 600×.

Where possible, genera and species were determined and a count was made of the foraminifera in several randomly selected areas of the slides. Only foraminifera which did not exceed 180 microns in the 80–200 mesh, and did not exceed 75 microns in the $<$ 200 mesh, were counted.

In the study of the Marianna samples the entire foraminiferal population was studied, before any attempt at identification of the microforaminifera was made. The majority of microforaminifera observed appeared to be taxonomically related to the foraminifera of the coarser fractions. In many cases, however, positive identifications of the microforaminifera to lower than generic rank were impossible.

Problems in identification arose from the fact that some of the tests of microforaminifera present in the Marianna samples seemed to possess so few chambers (in a few cases less than a single complete whorl was developed) that it was difficult to differentiate type of coiling.

As most microforaminifera are not flat, but conical or ellipsoidal in form, microscopic examination is limited by certain optical effects. The depth of focus is limited and decreases with an increase in power of the objective and size of opening of substage condenser aperture. No thorough examination of a microforaminifera can be accomplished without continuous adjustment of the focal plane and intensity of light.

The test structures of the microforaminifera are often obscured by extraneous material covering and filling

the chambers. In fact, calcareous particles adhering to tests may make a basic distinction between calcareous and arenaceous forms sometimes quite difficult.

Chamber number, surface ornamentation, sutures and pore shapes, are usually very clearly seen. Thickenings, such as those often present in the umbilical area, are not easily discernible; but wall structures and lamellid thickenings are sometimes very obvious. To some extent symmetry and coiling types may be determined by variation in light density and depth of focus.

Some workers have mounted specimens between coverslips to allow a view of each side of a given specimen. The mount is secured to a holder to permit recording microscope stage coordinates for relocating specimens. This type of mount facilitates the identification of some microforaminifera.

STATISTICAL STUDY OF COARSE AND FINE FRACTIONS

The statistical study of the coarse fractions of the Marianna limestone was made in order to: 1) determine the relative and absolute numbers of species and individuals present in the samples; 2) compare these forms with Bandy's (1949) results from the Little Stave Creek section; and, 3) determine the extent to which hydrofluoric acid selectively destroys arenaceous and/or calcareous tests.

Both fluoritized and water washed materials were studied in detail. The results are tabulated in Table 1. The number of individuals of each species is listed under the appropriate size fraction, with a distinction made between fluoritized (designated HF) and nonfluoritized (designated H_2O) preparations. To the right of each exact count, a letter denotes the relative abundance of the species in a particular volume of residue. The values assigned to these relative abundance designations are given in the Key to Table 1. The total number of specimens identified and the approximate volume of sample picked from each of the size fractions is also given in the Key. For comparison Table 1 also includes results obtained by Bandy from his study of the foraminifera of the two members.

A true comparison, however, of Bandy's data is not possible as Bandy does not indicate the amount of material used or the basis on which he designates the relative abundance. Although a greater diversity of forms were observed in the present study, the majority of species described by Bandy were found.

Bandy (1949, p. 15) lists the following species with common occurrences in the Marianna limestone: *Ammobaculites subagglutinans*, *Globorotalia mariannensis*, *Lepidocyclina mantelli* (Morton), *Planorbulina mediterranensis*, and *Uvigerina vicksburgensis*. Apparently the inclusion of *Planorbulina mediterranensis* in the list is an error, for he charts (Table 1) only "rare" and "doubtful" occurrences of the species. In the samples studied here, no specimens of *Lepidocyclina mantelli* or *Ammobaculites subagglutinans* were noted in either the fluoritized or nonfluoritized preparations. *Globorotalia mariannensis* and *Uvigerina vicksburgensis* were common in samples 1 and 2.

The coarse fractions of the Limestone member, sample 1, contain large numbers of *Cibicides*, especially *C.pippeni* and *C.* cf. *C. vicksburgensis*. Not as many, but still large numbers of *Spiroplectammina latior* and *S. alabamensis* also occur. The lagenids and rotalids show the greatest variety in the sample.

The foraminiferal faunule of the Mint Spring member, sample 2, is larger and shows more diversity than that of the Limestone member. *Cibicides*, especially *C. pippeni* and *C. lobatus* are dominant. *C. mississippiensis*, *Siphonina advena*, *Spiroplectammina latior*, *S. alabamensis*, *Planulina cocoaensis* and *P. subinflata* are also present in large numbers. The genus *Globigerina* shows greater abundance and variety than in the Limestone member. A large variety of other rotalids and lagenids are also present.

It will be noted on Table 1 that some natural discrepancy does exist between the data of the fluoritized and nonfluoritized material. Because no special techniques were employed to provide similar random samples for the preparations, this should be expected. In these Marianna samples, there is, however, no evidence of complete destruction of either calcareous or arenaceous tests by hydrofluoric acid, although in many instances the acid did corrode the surfaces. Several individual specimens were picked and fluoritized to confirm these results.

The statistical data on the abundance of the microforaminifera found in the fine fractions (80–200 and $<$ 200 mesh) is also tabulated in Table 1. Only fluoritized residues were used for this count; these stained more evenly than the water-washed material and were, therefore, easier to identify accurately. Identifications were made to the generic level, and where possible, to the specific level. The abundance of each genus is expressed as a percentage of the total number of identifiable specimens and is listed to the left of the letter designating the relative abundance of that genus. This percentage includes both the forms that could and could not be identified to species. The arbitrary basis for microforaminiferal abundance determinations is shown on Key to Table 1. In order to prevent anomalous conclusions concerning abundance, the following information is also included on the Key: total of percentages of each fraction; total number of identifiable foraminifera; total number of unidentifiable foraminifera; total number of foraminifera examined; and volumetric percentage of sample that is foraminiferal.

The results show that the majority of genera of microforaminifera also occur in the coarse fractions of the sample. An exception is *Guembelina* sp., which is only found in the fine fractions. Although it may be possible to get a rapid generic count from a slide of microforaminifera, it is doubtful that the species in the fine fractions of the samples used for this study could have been identified without comparison with specimens of the coarse fraction. As in the coarse fractions, the fine fractions of the Mint Spring member show a larger and more diverse foraminiferal population than in the Limestone member.

SIZE RELATIONSHIP OF MICROFORAMINIFERA TO OTHER FORAMINIFERA

In order to determine whether or not a definite, natural size boundary distinguishes microforaminifera from other foraminifera, tests of identifiable genera and species from a continuous series of coarser to finer fractions were measured. Although some genera were found to be more common in a given size range, others showed a continuous decrease in size, as well as a loss of distinctive test characters.

Length and width measurements from the largest to the smallest observable form were made on *Spiroplectammina alabamensis*, *S. latior* and *Uvigerina vicksburgensis*. In the present work *Uvigerina nuttalli* Cushman and Edwards, 1938, is considered to be a synonym of *U. vicksburgensis*. The synonymy, suggested by Bandy (1949, p. 143, p. 144) is justified by discovery of specimens from the Marianna limestone, Limestone member, exhibiting gradational characteristics between both species. The specimens possess a phialine lip and vary from length equalling 2.5 times the diameter to 1.0 times the diameter.

The actual measurements in microns for the forms are listed for comparison.

SIZE DISTRIBUTION — DIMENSIONS IN MICRONS

Spiroplectammina latior Length × Width Microns	*Spiroplectammina alabamensis* Length × Width Microns	*Uvigerina vicksburgensis* Length × Width Microns
770 × 410	574 × 392	806 × 338
756 × 378	546 × 518	686 × 336
742 × 420	546 × 392	658 × 336
742 × 392	532 × 490	630 × 336
742 × 364	532 × 434	616 × 336
742 × 322	532 × 378	616 × 294
728 × 364	504 × 378	616 × 280
686 × 420	492 × 342	602 × 294
672 × 384	492 × 323	599 × 289
672 × 322	476 × 406	588 × 294
658 × 588	462 × 392	588 × 280
657 × 378	460 × 369	574 × 294
657 × 350	448 × 364	574 × 280
645 × 420	448 × 350	560 × 378
616 × 378	434 × 350	560 × 308
588 × 420	434 × 322	546 × 322
588 × 308	420 × 378	546 × 280
574 × 364	420 × 364	535 × 235
556 × 321	420 × 350	518 × 308
546 × 308	420 × 322	518 × 280
532 × 392	392 × 336	504 × 308
532 × 364	392 × 322	492 × 375
518 × 392	392 × 294	488 × 308
518 × 308	378 × 350	482 × 420
504 × 364	378 × 308	448 × 308
504 × 336	378 × 294	448 × 294
504 × 322	364 × 322	448 × 280
504 × 308	364 × 294	439 × 278
490 × 462	364 × 280	434 × 308
490 × 378	350 × 308	434 × 294
490 × 350	350 × 294	434 × 280
477 × 364	342 × 278	396 × 268
476 × 378	336 × 322	392 × 294
476 × 322	336 × 252	378 × 238
476 × 308	322 × 294	364 × 266
439 × 235	321 × 289	364 × 252
434 × 308	321 × 257	353 × 268
406 × 350	310 × 225	353 × 225
406 × 308	308 × 294	350 × 252
406 × 266	300 × 246	342 × 257
392 × 350	294 × 308	336 × 238
392 × 336	268 × 225	322 × 252
392 × 394	268 × 128	308 × 252
364 × 322	246 × 268	308 × 238
364 × 280	193 × 128	308 × 224
350 × 308	182 × 171	300 × 203
321 × 128	153 × 133	257 × 112
308 × 336	97 × 138	230 × 112
278 × 118	87 × 87	225 × 102
278 × 102	87 × 61	224 × 133
273 × 123	71 × 122	214 × 64
268 × 128	66 × 97	194 × 122
260 × 128	61 × 66	193 × 128
230 × 179		192 × 118
214 × 77		184 × 112
199 × 102		173 × 112
189 × 87		171 × 118
179 × 87		171 × 117
179 × 51		168 × 117
173 × 71		163 × 117
163 × 87		163 × 112
163 × 77		163 × 107
153 × 82		161 × 112
153 × 71		153 × 92
150 × 171		148 × 102
143 × 138		139 × 96
133 × 128		128 × 128
123 × 123		128 × 82
118 × 150		92 × 77
117 × 117		86 × 64
107 × 122		
107 × 118		
107 × 107		
77 × 36		

In some size ranges more specimens were available so that measurements could be made for fine gradations. In general, however, the overall picture of the dimensions recorded show a constant, gradual decrease in size.

Less intensive measurements were made on several other identifiable genera and species to check the above results. In all cases, the size distribution indicated that no significant boundary existed to delimit "microforaminifera" from other foraminifera.

Thus the term "microforaminifera" might conveniently be retained as an operational term; it is used in this study to designate foraminifera less than 177 microns in size. Retention of the term "microforaminifera" seems justified, because the procedure of preparation and examination of material from this size range is ordinarily different from that of the larger size foraminifera.

LIFE CYCLE OF THE FORAMINIFERA

The microforaminifera may be intimately related to the life cycle of the foraminifera. It has been suggested that they belong to the megalospheric generation of the foraminifera.

Dimorphism is a common occurrence in foraminifera and it is known to result from metagenesis, the alternation of sexual and asexual generations in the life cycle. The two forms found in the foraminifera have been named on the basis of prolocular size; the megalospheric form, small test with large proloculus, and the microspheric form, large test with small proloculus.

Numerous nuclei are randomly distributed within the protoplasm of the microspheric form. At maturity the protoplasm leaves the test and each nucleus becomes surrounded by a sphere of protoplasm. Immediately before, or right after leaving the parental test the nucleated masses of protoplasm secrete a test. These are the megalospheres, and they are considerably larger than the zygotes resulting from the union of zoospores. The megalospheric forms remains uninucleate until maturity, at which time the nucleus draws a mass of protoplasm about itself and breaks down into many minute secondary nuclei. These nuclei leave the test as flagellate zoospores and conjugate to form zygotes or embryos of the microsphere.

Actually, however, in this simple alternation of generation, it is known that a series of megalospheric generations frequently separate the microspheric ones. Commonly, in successive megalospheric generations, the size of the megalospheric proloculus increases.

In most foraminifera, there exists a relationship between test morphology and the position of an individual in the life cycle. However, Le Calvez observed that in some cases metagenesis is not reflected in peculiarities of test morphology and must be noted cytologically in the living animal.

The fundamental cycle of dimorphism as briefly described above is well understood, although knowledge of elaborations remains inadequate. Hofker in 1925 suggested that two types of megalospheric forms with different prolocular dimensions may be produced in the foraminiferal life cycle. He used the symbol A_1 to designate the megalospheric form of larger diameter and A_2, that of smaller diameter. The symbol B denoted the microspheric form. Hofker thought that A_1 and A_2 each produced a different type of zoospore and that the conjugation of the two different types, heterogamy, was necessary to form the microsphere. Existence of the three distinct types A_1, A_2, and B was termed trimorphism. Later Hofker gave up the theory of heterogamy but insisted upon the validity of trimorphsm.

In collections from the Zuiderzee, Hofker (1930, 1948) observed that B forms of *Rotalia flevensis* live in the autumn and winter whereas the A_1 and A_2 forms exist in the spring and summer. On the basis of this information, a correlation between nuclear divisions, water temperature, and surface tension is suggested.

Variation in the type and extent of coiling development is correlated with prolocular dimensions. The forms with a small proloculus usually show more complete coiling than those with a large proloculus. Munier-Chalmas and Schlumberger apply the term *polymorphism initiale* to the phenomenon of variation in arrangement of the initial chambers, as is shown by the classic example of coiling variation in *Idalina antiqua* Schlumberger.

Some question might be raised over the correlation between asexual and sexual reproduction and the extent of coiling. Apparently the sexual nature of reproduction is not the only reason for repetition of the entire coiling sequence in the microspheric form, for, as Lister has suggested, the development of coiling in megalospheric forms is somewhat a function of the prolocular diameter. Hofker (1948, p. 513) suggests without explanation that the microspheric individuals have "the primitive characters possibly as a result of genetic factors or simply as a matter of size and space."

With regard to the growth of the individual chambers in foraminifera, Le Calvez (1938) has shown that the volume of a newly added chamber is proportional to the volume of protoplasm in the preceding chamber.

In order to determine the extent to which the above theories are applicable to the microforaminifera, a number of more intensive studies were made. It was previously noted that the measurements made on *Uvigerina vicksburgensis*, *Spiroplectammina alabamensis* and *S. latior* indicated that no natural size boundary exists to delimit the microforaminifera from other foraminifera.

The second considerations studied concerned prolocular dimensions with relationship to length and width, and the extent of coiling in various genera. In general these results indicated that most microforaminifera, with the exception of *Eponides*, possess a comparatively large proloculus. With regard to the extent of coiling, it was observed, although not within a single genus or species, that the amount of coiling tends to diminish to 5-, 4-, 3-, 2-, and what was interpreted to be a 1-chambered stage, i.e., a proloculus. Photomicrographs illustrate specimens of such coiling: *Guembelina*, 5-chambered (pl. 1, fig. 15), *Spiroplectammina latior*, 4-chambered (pl. 1, fig. 2), *Robulus*, 4-chambered (pl. 1, fig. 8) and *Guembelina*, 3-chambered (pl. 1, fig. 14). On plate 2 are illustrated megalospheric forms (figs. 18–22) so little differentiated that generic identification is impossible. Plate 2, fig. 23 illustrates a spherical shell, interpreted to be a proloculus.

A spherically shaped microfossil of uncertain affinity is illustrated as fig. 24 on pl. 2. The object has four subchambers or areas demarked by thinning of the wall; the four areas are tetrahedrally disposed.

A thorough study of *Spiroplectammina latior* was made and the detailed measurements, length, width, prolocular diameter, and number of chambers are listed as follows:

Spiroplectammina latior
All measurements in microns

Length × Width	Prolocular diameter	Number of chambers
358 × 235	46	17
292 × 342	25	15
289 × 278	36	15
289 × 257	64	9
235 × 225	54	10
235 × 225	33	13
235 × 193	32	14
225 × 225	38	11
214 × 214	43	10
214 × 182	32	11
205 × 205	48	8
193 × 193	48	9
193 × 161	25	16
193 × 171	42	9
187 × 155	41	9
184 × 163	38	10
177 × 150	25	13
171 × 182	41	9
171 × 161	48	7
161 × 182	61	6
150 × 171	62	6
150 × 171	48	8
150 × 171	59	6
143 × 138	20	13
133 × 128	26	10
123 × 123	36	8
118 × 150	65	4
117 × 117	31	8
117 × 182	43	8
107 × 107	37	7
107 × 107	31	11
107 × 122	36	6
107 × 118	32	6
86 × 107	37	4

This tabulation shows that the prolocular dimensions throughout the series are relatively large but vary irregularly. There appears to be little relationship between the size of the test and the size of the proloculus or size of test and chamber number, with the exception of the largest form measured. There does, however, seem to be some relationship between the size of the proloculus and the number of chambers. The individuals with largest proloculi have fewer chambers, and as the prolocular dimensions decrease the number of chambers increase. It was also noted in this intense study of *Spiroplectammina latior* that the species does not show initial polymorphism; a constant number of planispiral chambers (3 plus a proloculus) were developed regardless of the size of the proloculus or test. It was noted, however, that as the size of the megalosphere increased, the biserial chamber development decreased. No stages less differentiated than that of the megalosphere with planispiral coiling (pl. 1, fig. 2) were observed. It seems

KEY TO TABLE 1

Designations used in coarse fraction

Abundance: sample 1 and 2: d – doubtful; r – rare; c – common; a – abundant; va – very abundant.

Arbitrary basis for abundance determinations in sample 1

> 40 mesh fractions

r – 1 or 2 specimens/ 8cc. residue
c – 3 to 5 specimens / 8cc. residue
a – 6 to 10 specimens / 8cc. residue
va – 11 or more specimens / 8cc. residue

40–60 and 60–80 mesh fractions

r – 1 or 2 specimens / 1cc. residue
c – 3 to 20 specimens / 1cc. residue
a – 21 to 50 specimens / 1cc. residue
va – 51 or more specimens / 1cc. residue

Arbitrary basis for abundance determinations in sample 2

> 40 mesh fraction

r – 1 or 2 specimens / 8cc. residue
c – 3 to 5 specimens / 8cc. residue
a – 6 to 18 specimens / 8cc. residue
va – 19 or more specimens / 8cc. residue

40–60 and 60–80 mesh fractions

r – 1 to 10 specimens / 1cc. residue
c – 11 to 49 specimens / 1cc. residue
a – 50 to 100 specimens / 1cc. ersidue
va – 100 or more specimens / 1cc. residue

Sample 1	> 40		40–60		60–80	
	H_2O	HF	H_2O	HF	H_2O	HF
Total no. of specimens	113	90	248	280	230	191
Approx. vol. of sample picked	8cc.	8cc.	1cc.	1cc.	1cc.	1cc.

Sample 2	> 40		40–60		60–80	
	H_2O	HF	H_2O	HF	H_2O	HF
Total no. of specimens	299	224	835	1151	1731	1752
Approx. vol. of sample picked	8cc.	8cc.	1cc.	1cc.	1cc.	1cc.

Arbitrary basis for microforaminiferal abundance determinations

r – 0.0% to 4.9% of the identifiable specimens
c – 5.0% to 9.9% of the identifiable specimens
a – 10.0% to 19.9% of the identifiable specimens
va – 20.0% or more of the identifiable specimens

	Sample 1		Sample 2	
	80–200	< 200	80–200	< 200
Total of the percentages listed Table 1.	99.8%	110.5%	98.1%	100.1%
Total no. identifiable foraminifera.	235	142	145	139
Total no. unidentifiable foraminifera.	115	605	34	598
Total no. foraminifera examined.	350	747	179	737
Volumetric % of sample that is foraminiferal	45%	25%	60%	25%

SAMPLE 1	BANDY		SAMPLE 2	BANDY		SAMPLE 1						MICROFORAMINIFERA	SAMPLE 1		SAMPLE 2						MICROFORAMINIFERA	SAMPLE 2	
						>40		40-60		60-80			80-200	<200	>40		40-60		60-80			80-200	<200
LIMESTONE MEMBER	66	67	MINT SPRINGS MEMBER	64	65	H_2O	HF	H_2O	HF	H_2O	HF		HF	HF	H_2O	HF	H_2O	HF	H_2O	HF		HF	HF
Alabamina scitula			Alabamina scitula							3C							2R	1R	20C	9R			
Ammobaculites subagglutinans	C		Ammobaculites subagglutinans	C																			
												Angulogerina	0.9R								Angulogerina	2.8R	2.2
Angulogerina byramensis	C		Angulogerina byramensis	C	C						1R								27C	11C			
			A. vicksburgensis	C	R														1R		A. vicksburgensis	0.7R	
												Anomalina	1.3R	0.7R							Anomalina	2.1R	2.9R
Anomalina bilateralis	C	C	Anomalina bilateralis	C	C	3C	2R	6C	21A	17C	14C				1R		11C	18C	90A	52A	A. bilateralis	0.7R	
Asterocalus sublituus										3C													
																					Baggina (?)	2.8R	0.7R
			Biforina vicksburgensis	R															1R				
			Bitubulogerina howei	C															2R		Bitubulogerina	1.4R	0.7R
												Bolivina	100A	42R							Bolivina	62C	11.5C
Bolivina mississippiensis	R		Bolivina mississippiensis	C	C				1R		1R									1R			
			B. retifera	R	R												16C	54A	1R	4R	B. retifera	1.4R	3.6R
B. striatellata			B. striatellata							4C	1R								1R		B. striatellata	0.7R	
			Bolivinella subpectinata																2R				
			Bulimina byramensis	C																			
			B. socialis		R														1R	1R			
												Concris	0.9R	0.7R							Concris	1.4R	1.4R
Concris sagra										1C													
			Cassidulina moodyensis																1R				
																					Ceratobulimina	1.4R	
			Chrysalogonium vicksburgense																	1R			
												Cibicides	8.9C	21.0VA							Cibicides	4.8R	17.3A
			Cibicides choctawensis														1R		2R	1R			
Cibicides cookei	R	R	C. cookei	C	C	15VA	7A								58VA	43VA	43C	22C	3R	10R			
C. lobatus	d	d	C. lobatus	d	d		1R	2R	1R		2R	C. lobatus	2.9R	5.6C	1R		38C	50A	165VA	278VA	C. lobatus	3.4R	
C. pippeni	a	a	C. pippeni	C	a	2R	20VR	55VA	104VA	31A	34A	C. pippeni	2.9R	0.7R	56VA	18A	235VA	235VA	256VA	234VA			
			C. pseudoungerianus	C												12A	1R						
C. cf C. vicksburgensis	C	C	C. cf C. vicksburgensis	C		1R	6A	6C	4C	8C	12C				1R		3R		2R	4R			
C. sp. A			C. sp. A							5C	1R								43C	19C			
Cibicidina danvillensis										2R		Cibicidina	1.8R								Cibicidina	1.4R	0.7R
C. mississippiensis	C	C	Cibicidina mississippiensis	C	C		1R	19C	25A	24A	32A	C. mississippiensis	1.8R				7R	11C	121VA	114VA	C. mississippiensis	1.4R	0.7R
												Dentalina	1.3R										
			Dentalina cf. D. communis	R															1R				
			Demacista																	1R			
			D. indifferens	R	C														1R				
			D. monroei															1R					
Dentalina soluta			D. soluta	R	R					1R													
D. vertebralis albatrossi	R	D	D. vertebralis albatrossi	R	R	2R	3C		3C						7A	1R	5R	2R		1R			
			Dimorphina danvillensis subtenis																1R				
			Ellipsopleurostomella sp.															1R					
												Entosolenia	0.4R								Entosolenia	0.7R	
			Entosolenia orbignyana var. flintii														2R	4R		1R			
												Eponides	14.0A	11.3A							Eponides	7.6R	9.4C
Eponides ellisorae	R	R	Eponides ellisorae	C	C	1R	1R	3C	3C						3C	6C	34C	51C	26C	19C			
Frondicularia garrattí											1R												
Gaudryina stavensis	C	R	Gaudryina stavensis	C		7A	5C			1R					9A	7A	11C	24C	1R	4R			
			Gaudryina sp.																3R				
												Globigerina	14.0A	7.7C							Globigerina	24.8VA	6.3C
Globigerina bulloides	C	C	Globigerina bulloides		C	1R		15C	7C	4C		G. bulloides	2.1R	0.7R			1R		3R	13C	G. bulloides	2.1R	
			G. dissimilis	R													1R		2R	1R			
			G. eocaenica	R													1R		3R	1R	G. eocaenica	1.4R	
G. increbescens	C		G. increbescens	C	C	1R	1R	10C	1R	1R	7C	G. increbescens	2.6R				2R	8R	9R	21C	G. increbescens	1.4R	
			G. ouachitaensis		C												1R	4R	13C	10R	G. ouachitaensis	1.4R	
			G. ouachitaensis senilis	R	R												1R	10R	3R	20C			
			G. rotundata jacksonensis	R														1R		4R			
			G. triloculoris	R	R										2R	2C	9C	26C	18C	23C	G. triloculoris	2.8R	
												Globorotalia	0.4R										
Globorotalia mariancensis	a	a	Globorotalia mariancensis	C	a	4C	5C				1R				34VA	41VA	21C	27C	31C	22C			
												Gumbelina	21.1VA	28.2VA							Gumbelina	4.8R	53.8VA
												Guttulina	0.4R	0.7R									
Guttulina byramensis	C	C	Guttulina byramensis	C	C	5C		1R		7C	1R				1R		6R	14C	3R	5R			
G. hantkeni	C		G. hantkeni	R				2R	1R							1R		1R		1R			

D. vertebralis albatrossi	R	D	D. vertebralis albatrossi	R	R	2 R	3 C		3 C						7 A	1 R	5 R	2 R		1 R			
			Dimorphina donvillensis subfenia																1 R				
			Ellipsopleurostomella sp.															1 R					
												Entosolenia	0.4 R				2 R				Entosolenia	0.7 R	
			Entosolenia orbignyana var flintii															4 R		1 R				
Eponides ellisorae	R	R	Eponides ellisorae	C	C	1 R	1 R	3 C	3 C			Eponides	14.0 A	11.3 A	3 C	6 C	34 C	51 C	26 C	15 C	Eponides	7.6 R	9.4 C
Frondicularia garretti											1 R												
Gaudryina stavensis	C	R	Gaudryina stavensis	C		7 A	5 C			1 R					9 A	7 A	11 C	24 C	1 R	4 R			
			Gaudryina sp.																3 R				
												Globigerina	14.0 A	7.7 C							Globigerina	24.8 VA	6.3 C
Globigerina bulloides	C	C	Globigerina bulloides		C	1 R		15 C	7 C	4 C		G. bulloides	2.1 R	0.7 R			1 R		3 R	13 C	G. bulloides	2.1 R	
			G. dissimilis	R													1 R		2 R	1 R			
			G. eocaenica	R													1 R		3 R	1 R	G. eocaenica	1.4 R	
G. increbescens	C		G. increbescens	C	C	1 R	1 R	10 C	1 R	1 R	7 C	G. increbescens	2.6 R				2 R	8 R	9 R	21 C	G. increbescens	1.4 R	
			G. ouachitaensis		C												1 R	4 R	13 C	10 R	G. ouachitaensis	1.4 R	
			G. ouachitaensis senilis	R	R												1 R	10 R	3 R	20 C			
			G. rotundata jacksonensis	R														1 R		4 R			
			G. trilocularis	R	R												2 R	2 C	9 C	26 C	18 C	23 C	G. trilocularis	2.8 R	
												Globorotalia	0.4 R										
Globorotalia mariannensis	a	a	Globorotalia mariannensis	C	a	4 C	5 C				1 R				34 VA	41 VA	21 C	27 C	31 C	22 C			
												Gumbelina	21.1 VA	28.2 VA							Gümbelina	4.8 R	33.8 VA
												Guttulina	0.4 R	0.7 R									
Guttulina byramensis	C	C	Guttulina byramensis	C	C	5 C		1 R		7 C	1 R				1 R		6 R	14 C	3 R	5 R			
G. hantkeni	C		G. hantkeni	R				2 R	1 R							1 R		1 R		1 R			
			G. praelonga																	2 R			
G. sp.								1 R															
												Gyroidina	3.0 R	2.1 R									
Gyroidina obesa	R		Gyroidina obesa	R	R	8 A		1 R	2 R	1 R					9 A	4 C	9 R	9 R	2 R		Gyroidina	0.7 R	
																					G. obesa	0.7 R	
			Karreriella advena	C														5 R		2 R			
			Lagena humerifera	R															1 R				
			L. laevis stavensis																1 R				
			L. wallacei	R																			
Lepidocyclina mantelli	C	C																					
Liebusella byramensis turgida	C	R	Liebusella byramensis turgida	C	R	16 VA	7 A	1 R							35 VA	51 VA	4 R	1 R	1 R	3 R			
Marginulina hantkeni																							
			Marginulina multiplicata	R				1 R												1 R			
M. sp.			M. sp.			2 R												1 R					
																					Massilina	1.4 R	
			Massilina decorata	C	R													16 C	15 C	2 R			
Nodosaria cf. N. latejugata																							
			Nodosaria latejugata	R	R	1 R														1 R			
																					Nonion	3.4 R	

			Massilina decorata	C	R													16 C	15 C	2 R	Massilina	1.4 R		
Nodosaria cf N. latejugata			Nodosaria latejugata	R	R	1 R														1 R				
			Nonion advenum																	1 R	Nonion	3.4 R		
			N. nicobarensis	R	R												2 R		16 C	7 R	N. nicobarensis	2.1 R		
			Nonionella jacksonensis									Nonionella	0.4 R						1 R		Nonionella	0.7 R	0.7 R	
			N. oligocenica																	1 R				
Nonionella spissa			N. spissa	R	R					2 R									2 R					
Oolina spherica			Oolina spherica								1 R				1 R					1 R				
Palmula hanbesti	C	R	Palmula hanbesti	C	R	9 A	3 C	10 C	6 C	14 C	6 C						5 C	4 C	14 C	20 C	9 R	55 A			
Pianorbulina larvata						1 R	1 R	2 R																
P. mediterranensis	D	R						1 R	1 R															
												Pianulina	85 C	35 R							Pianulina	9.0 C	2.2 R	
Pianulina cocoaensis	R	R	Pianulina cocoaensis			1 R	1 R	5 C	5 C	2 R	6 C	P. cocoaensis ?	0.9 R	0.7 R	22 VA	14 A	94 A	95 A	45 C	41 C	P. cocoaensis ?	2.8 R		
P. subinflata		R	P. subinflata	C				3 C	1 R	1 R		P. subinflata	7.6 C	2.1 R	5 C	1 R	12 C	10 C	43 C	28 C	P. subinflata	6.2 C		
												Polymorphina	0.4 R	1.4 R							Polymorphina	1.4 R		
			Polymorphina advena															1 R						
			P. frondea														1 R		4 R	6 R				
Polymorphina nuda			P. nuda	R	R					1 R	2 R													
Pullenia alazonensis			Pullenia alazonensis							1 R	1 R						1 R	1 R	14 C	11 C				
Pyrulina albatrossi										1 R														
Raphanulina gibba	R		Raphanulina gibba	R	R			2 R		3 C	1 R	Raphanulina	0.4 R		4 C	2 R		10 C	5 R	7 R	Raphanulina	0.7 R		
			R. inequalis												2 R			2 R	3 R					
			Romulina globifera														1 R	1 R	2 R	1 R				
												Robulus	2.5 R								Robulus	0.7 R		
Robulus alato-limbatus			Robulus cf. alato-limbatus			2 R	4 C										2 R	8 R						
R. carolinianus			R. carolinianus			4 C	3 C								2 R	2 R	2 R	3 R	1 R	1 R				
			R. convergens	C	R										6 A	2 R	10 R	16 C	24 C	28 C				
R. euglypheus	R		R. euglypheus	R	R													1 R						
			R. inusitatus												1 R									
R. limbosus	R		R. limbosus	C	C													4 R	5 R	9 R				
R. pseudovortex	R	R	R. pseudovortex		R			12 C	8 C	17 C	9 C	R. pseudovortex	1.3 R		8 A	3 R	6 R	16 C	5 R					
R. vicksburgensis	a	R	R. vicksburgensis	A	A	9 A	3 C	5 C	11 C	6 C	3 C					2 R	10 R	13 C	6 R	4 R				
R. vicksburgensis var. aperta			R. vicksburgensis var. aperta					1 R										1 R	5 R	5 R				
			Rotorbinella packardi	R											2 R	3 R								
Saracenaria moresiana						1 R	2 R				1 R													
S. stavensis	R		Saracenaria stavensis	R			1 R	1 R		2 R	2 R				2 R		3 R			4 R				
												Siphonina	2.1 R								Siphonina	1.4 R	2.9 R	
Siphonina advena	C	C	Siphonina advena	C	C			28 A	40 A	23 A	26 A						112 VA	180 VA	274 VA	286 VA	S. advena	1.4 R		
			Siphonodosaria puntensis															1 R						
												Spiroplectammina	0.4 R	2.1 R							Spiroplectammina	6.2 C		
Spiroplectammina alabamensis	C	C	Spiroplectammina alabamensis	C	C			9 C	8 C	17 C	17 C						3 R	30 C	119 VA	156 VA	S. alabamensis	2.1 R		
S. latior	C	C	S. latior	C	C	2 R		21 A	17 C	20 C	11 C	S. latior	0.9 R	2.1 R	1 R	2 R	45 C	26 C	69 VA	138 VA	S. latior	4.2 R		
S. mississippiensis	R																							
			Textularia conica									Textularia	1.8 R	0.7 R			1 R		3 R		Textularia	6.2 C	2.9 R	
Textularia subhaueri			T. subhaueri			13 VA	9 A								21 VA	21 VA								
Textularia(?)								1 R																
												Uvigerina	4.7 R	2.1 R							Uvigerina	3.7 R	1.4 R	
Uvigerina nuttalli	C		Uvigerina nuttalli	D	D																			
U. vicksburgensis	C	C	U. vicksburgensis	C	R	2 R	4 C	18 C	10 C	7 C	6 C	U. vicksburgensis	4.7 R	0.7 R		2 R	14 C	60 A	8 R	15 C	U. vicksburgensis	0.7 R	3.4 R	
																					Valvulineria	0.7 R		
			Valvulineria octocamerata	C	C												34 C	83 A	90 A	54 A	V. octocamerata	0.7 R		
												Virgulina	1.8 R	12.0 A							Virgulina	2.9 R		
			Virgulina dibollensis	R																				

TABLE I: Comparison of relative abundance of Foraminifera in the various size fractions of samples 1 and 2.

TABLE I

possible that such a loss of coiling, with increase in the size of the megalosphere, may have resulted in the formation of the 3-, 2,- and 1-chambered forms observed in the Marianna limestone.

Although one thorough investigation does not give sufficient evidence for conclusive proof, the results of this study do suggest that the microforaminifera belong to the described taxons of foraminifera. As a part of the life cycle of the foraminifera, they might represent successive megalospheric generations that did not grow to norm for the genus.

Environmental conditions and even seasonal changes might be intimately related to the presence, abundance or the absence of the microforaminifera with relation to the larger foraminifera. Environmental factors, such as nutrients, water temperature, chemical composition and physical condition of the water, hydrogen-ion concentration (pH) and light could conceivably affect successive nuclear division of these protozoans, giving rise to several megalospheric generations, each with proportionately larger proloculi, smaller test and less differentiation in coiling.

In their study of the sedimentary belts of Kapingamarangi Atoll, McKee, Chronic, and Leopold (1959, p. 544) discuss some significant factors concerning the relationship of the microforaminifera to some specific environments: "Microforaminiferal remains are especially common in sediments from shallow-water stations (20 feet) of the *Amphistegina madagascariensis* zone, and at stations where the water is deepest (calcium carbonate mud, 200–240 feet). In other facies, including the *A. lessonii* zone, microforaminifera are not consistently numerous. In shallow-water occurrences the microforaminifera might represent youthful specimens of *A. madagascariensis;* however, in the deep-water zone of calcium carbonate mud, where no large foraminifers occur, microforaminifera may be the result of environmentally induced dwarfism that is observed in many modern collections of deep-water organisms. The graphic data (fig. 21) indicate that microforaminifers are present or numerous in facies zones where large foraminifers are not the dominant organisms; this fact at least suggests that the bulk of microforaminiferal populations in these zones may be taxonomically separate from the common megaforaminifera of the lagoon."

In the present investigation, environmental factors are considered one of the most important aspects of a study of the microforaminifera. It is certainly feasible to expect, under some environmental conditions, that the microforaminifera would represent the dominant part of the population as compared with the larger foraminifera. This factor, in itself, however, does not seem to be sufficient justification for separating taxonomically the microforaminifera from other foraminifera. In order to establish more specific relationships, further detailed work is necessary on both living and fossil populations.

PALEOECOLOGY

The lithology and fossil content of samples 1 and 2 suggest that at Little Stave Creek, the Marianna limestone was deposited in a shallow, unrestricted sea. The clear, calm, waters teemed with a biocoenose dominated by bryozoans, foraminifera and algae. Ostracodes and sponges formed minor elements of the faunal assemblage, plant fossils were almost completely absent.

Large numbers of benthonic foraminifera indicate favorable physical and chemical conditions. Two of the benthonic species, *Cibicides lobatulus* (Walker and Jacob) and *Planorbulina mediterranensis* d'Orbigny, are believed by Carter (1951, p. 246) to grow dorsally attached to certain algae. Such a mode of growth restricts the living foraminifera to depths not exceeding 100 meters, which, in clear waters, is approximately the lower limit of light penetration in quantities sufficient for effective photosynthesis.

The purity of the carbonate sediment and the occurrence of the pelagic, open-sea species of *Globigerina* and *Globorotalia* (which constitute 5% and 6½% of the foraminiferal assemblages from the coarser fractions of sample 1 and 2, respectively) suggest the absence of land barriers seaward, as well as proximate rivers. The free circulation of the neritic waters with the open sea effected minor mixing of faunal elements from adjacent biotopes. Circulation was, however, insufficient to extensively erode or sort the microfossils.

The climate probably varied from subtropical to temperate. The large number of bryozoans lends support to the general paleoecological conclusions based on the foraminifera, namely, that the Marianna limestone was deposited in shallow, clear, temperate or subtropical waters.

The close correspondence between the environments of deposition of the Mint Spring and Limestone members of the Marianna limestone is reflected by their lithologic and faunal similarities. Both are essentially microcoquinas consisting dominantly of foraminiferal and bryozoan fossils. Of the 54 species of foraminifera occurring in the sample of the Limestone member (sample 1), 40 were observed to occur in the Mint Spring sample (sample 2). In addition, the foraminiferal species which dominate the Limestone member were dominant faunal elements during the deposition of the Mint Spring member.

That minor differences in the environments of deposition of the members did exist is evident from the variation in absolute and relative abundance of the foraminiferal species occurring in the two members. Sample 2 coarse fractions contain about 50% more species and 600% more individuals than sample 1. The following genera are abundant in sample 2 and subordinate or absent in sample 1: *Angulogerina*, *Bolivina*, *Nonion*, and *Massilina*. Although the percentage of pelagic individuals from the Mint Spring does not differ appreciably from that of the Limestone member, a greater diversity of species exists in the former.

Differences in bryozoan content of the two members were also noted. Fewer bryozoans are present in the Mint Spring sample than in the Limestone sample.

A comparison of the ostracodal assemblages recovered from samples 1 and 2 show no appreciable differences. Sample 2 contains a larger number of specimens in both the fluoritized and unfluoritized material, but the fauna is similar to that found in sample 1. The environment of deposition suggested by the ostracodes agrees with that of the foraminifera.

SUMMARY AND CONCLUSIONS

The foraminiferal population of the Marianna limestone, Limestone and Mint Spring members, reveals a close relationship between the microforaminifera and other foraminifera present in the samples. Most microforaminifera could be identified by comparison with individuals of larger test dimensions; 25 genera and 22 species occurred in both coarse and fine fractions of the prepared samples. The microforaminiferal group consists dominantly of megalospheric forms of the Rotaliidae and Anomalinidae.

No significant natural size boundary for the delimitation of the microforaminifera was noted. In fact, some species show polymorphic series exhibiting a more or less continuous decrease in size as well as loss of differentiation and distinctive test characters with decreasing test size. Tests observed to consist of as few as 5, 4, 3, 2, or 1 chamber(s) may represent the ultimate loss of test differentiation by the megalospheric generations directly preceding sexual reproduction. This theory, however, is based on the assumption that the observed specimens are mature forms.

The faunal assemblages present in the Mint Spring and Limestone members suggest that deposition was in shallow, clear, temperate or subtropical waters in an open sea.

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(continued on page 414)

EXPLANATION OF PLATES

None of the photographs are retouched. The location of specimens on the slides is designated by the distance of the photographed specimen toward the right edge of the slide by the distance of the specimen toward the lower edge of the slide. All distances are measured in millimeters from the upper left corner of the coverslip.

PLATE 1

1 *Spiroplectammina latior*
Slide 1 80–200–1, location: 10.4 mm. × 3.2 mm. Focused on the periphery, × 200.

2 *Spiroplectammina latior*
Slide 2 80–200–5, location: 2.6 mm. × 12.9 mm. Focused on the periphery, × 200.

3 *Spiroplectammina latior*
Slide 1 80–200–5, location: 3.8 mm. × 18.1 mm. Focused on the periphery, × 200.

4 *Textularia* sp.
Slide 1 < 200–4, location: 16.4 mm. × 1.1 mm. Focused on early sutures, × 400.

5 *Textularia* sp.
Slide 1 80–200–6, location: 8.9 mm. × 0.9 mm. Focused on the periphery, × 200.

6 *Textularia* sp.
Slide 1 80–200–6, location: same field as fig. 5. Focused on the periphery, × 200.

7 *Textularia* sp.
Slide 1 < 200–2, location: 12.4 mm. × 3.0 mm. Focused on the periphery, × 400.

8 *Robulus* sp.
Slide 2 < 200–1, location: 2.8 mm. × 2.9 mm. Focused on the periphery, × 200.

9 *Robulus pseudovortex*
Slide 1 80–200–1, location: 14.9 mm. × (–0.3 mm.). Focused on the periphery, air bubbles in three chambers, × 200.

10 *Dentalina* sp.
Slide 1 < 200–1, location: 15.7 mm. × 11.8 mm. Focused on the periphery, all chambers except deuteroconch filled with air bubbles, × 200.

11 *Raphanulina* sp.
Slide 2 80–200–1, location: 13.8 mm. × 4.5 mm. Focused on the periphery, × 200.

12 *Polymorphina* sp.
Slide 2 80–200–1, location: 0.7 mm. × 17.3 mm. Focused on the periphery, proloculus filled with glauconite, × 200.

13 *Nonionella* sp.
Slide 1 80–200–1, location: 8.9 mm. × 4.2 mm. Focused on the periphery, × 200.

14 *Guembelina*(?) sp.
Slide 2 < 200–3, location: 8.7 mm. × 9.4 mm. Focused on the periphery, × 800.

15 *Guembelina* sp.
Slide 1 < 200–2, location: 6.8 mm. × 9.2 mm. Focused on the periphery, × 400.

16 *Guembelina* sp.
Slide 1 < 200–1, location: 1.3 mm. × 1.3 mm. Focused on the periphery of the last pair of chambers, × 200.

17 *Entosolenia* sp.
Slide 1 80–200–2, location: 6.1 mm. × 10.3 mm. Focused on the internal tube, × 200.

18 *Virgulina* sp.
Slide 1 < 200–2, location: 13.0 mm. × 11.6 mm. Focused on the periphery, × 400.

19 *Bolivina striatellata*
Slide 2 80–200–7, location: 5.2 mm. × 3.3 mm. Focused on the costae, × 200.

20 *Bolivina* sp.
Slide 1 < 200–2, location: 4.4 mm. × 16.2 mm. Focused on the sutures, × 200.

21 *Bitubulogenerina* sp.
Slide 2 80–200–2, location: 5.4 mm. × 11.5 mm. Focused on the periphery, × 200.

22 *Uvigerina* sp.
Slide 1 80–200–6, location: 7.5 mm. × 8.4 mm. Focused on the periphery, × 200.

23 *Uvigerina vicksburgensis*
Slide 2 80–200–1, location: 5.1 mm. × 16.5 mm. Focused on the final chamber, × 200.

24 *Angulogerina vicksburgensis*
Slide 2 80–200–5, location: 6.9 mm. × 7.0 mm. Focused on the periphery, × 200.

25 *Valvulineria octacamerata*
Ventral view. Slide 2 80–200–3, location: 11.1 mm. × 1.2 mm. Focused on the periphery, × 200.

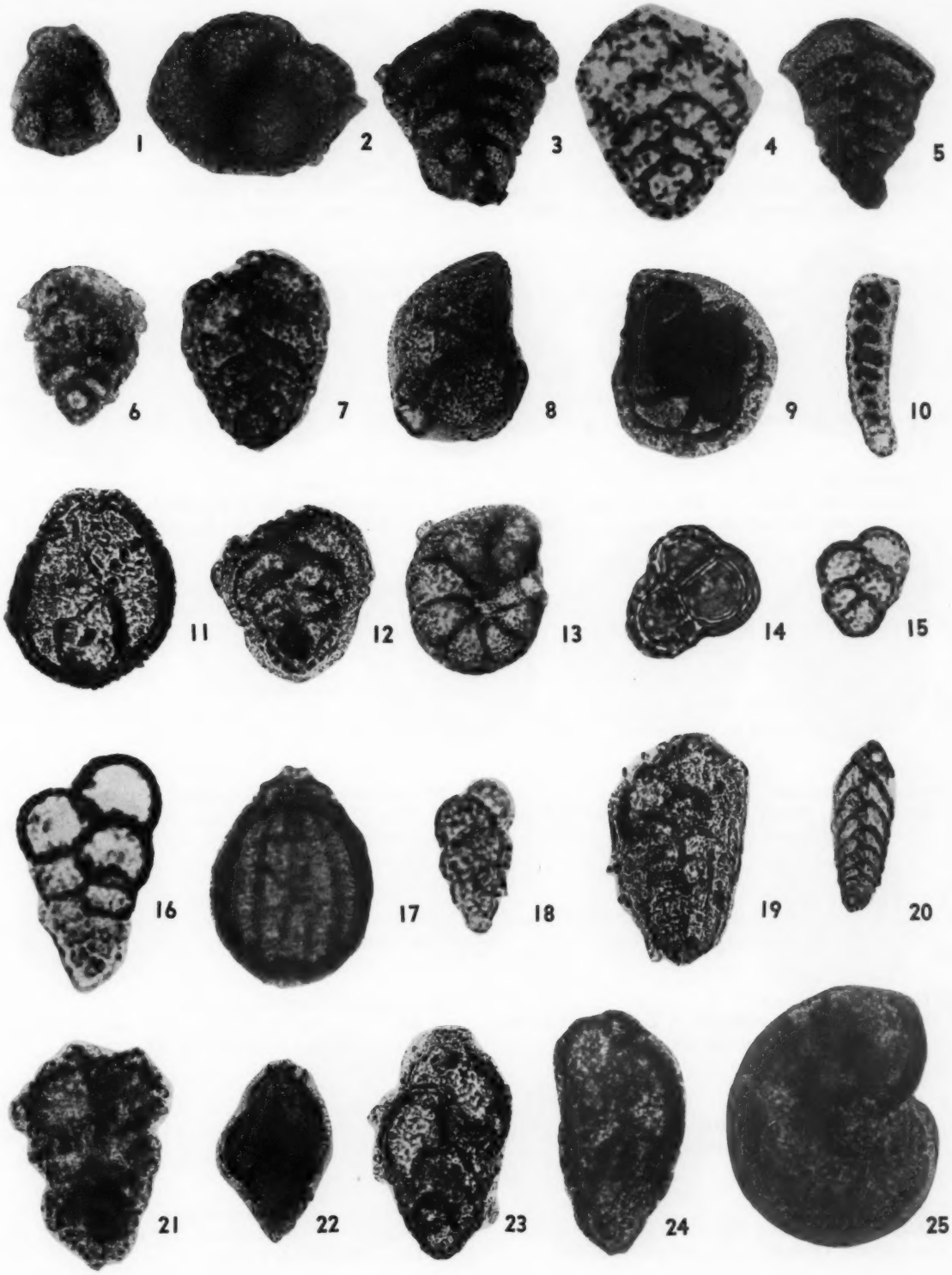
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PLATE 2

1 *Gyroidina* sp.
Peripheral view. Slide 1 < 200–2, location: 4.2 mm. × 9.7 mm. Focused on the proloculus, × 400.

2 *Eponides* sp.
Ventral view. Slide 1 < 200–4, location 7.9 mm. × 12.2 mm. Focused on the periphery, × 400.

3 *Eponides* sp.
Ventral view. Slide 1 < 200–1, location: 1.9 mm. × 2.9 mm. Focused on the periphery, × 200.

4 *Siphonina* sp.
Ventral view. Slide 1 < 200–1, location: 1.8 mm. × 5.6 mm. Focused on the periphery, × 400.

5 *Cancris*(?) sp.
Ventral view. Slide 1 < 200–2, location: 8.2 mm. × 10.9 mm. Focused on the periphery, × 400.

6 *Baggina*(?) sp.
Dorsal view. Slide 2 80–200–5, location: 2.3 mm. × 6.3 mm. Focused on the periphery.

7 *Ceratobulimina*(?) sp.
Ventral view. Slide 2 80–200–6, location: 3.6 mm. × 14.5 mm. Focused on the aperture, × 200.

8 *Globigerina bulloides*
Dorsal view. Slide 2 80–200–3, location: 10.6 mm. × 3.7 mm. Focused on the periphery, × 200.

9 *Globigerina bulloides*
Ventral view. Slide 1 80–200–2, location: 12.6 mm. × 13.3 mm. Focused on the first whorl, × 200.

10 *Globigerina increbescens*
Dorsal view. Slide 2 80–200–3, location: 15.9 mm. × 9.3 mm. Focused on the periphery, × 200.

11 *Anomalina* sp.
Dorsal view. Slide < 200–1, location: 15.9 mm. × 2.0 mm. Focused on the periphery, × 200.

12 *Anomalina* sp.
Dorsal view. Slide 1 80–200–1, location: 2.3 mm. × 7.6 mm. Focused on the periphery, × 200.

13 *Planulina subinflata*
Dorsal view. Slide 1 < 200–4, location: 9.8 mm. × 11.2 mm. Focused on the periphery, × 400.

14 *Planulina cocoaensis*(?)
Dorsal view. Slide 1 80–200–1, location: 10.0 mm. × 4.3 mm. Focused on the periphery, × 200.

15 *Cibicidina mississippiensis*
Dorsal view. Slide 1 80–200–1, location: 0.5 mm. × 7.7 mm. Focused on the periphery, × 200.

16 *Cibicides lobatus*
Dorsal view. Slide < 200–2, location: 13.6 mm. × 6.5 mm. Focused on the periphery, × 400.

17 *Cibicides lobatus*
Dorsal view. Slide 1 80–200–1, location: 1.7 mm. × 0.5 mm. Focused on the periphery, × 200.

18 Undifferentiated foraminifer
Slide 1 200–2, location: 6.3 mm. × 8.3 mm. Focused on the periphery, × 400.

19 Undifferentiated foraminifer
Slide 1 < 200–2, location: 6.9 mm. × 9.2 mm. Focused on the periphery, × 400.

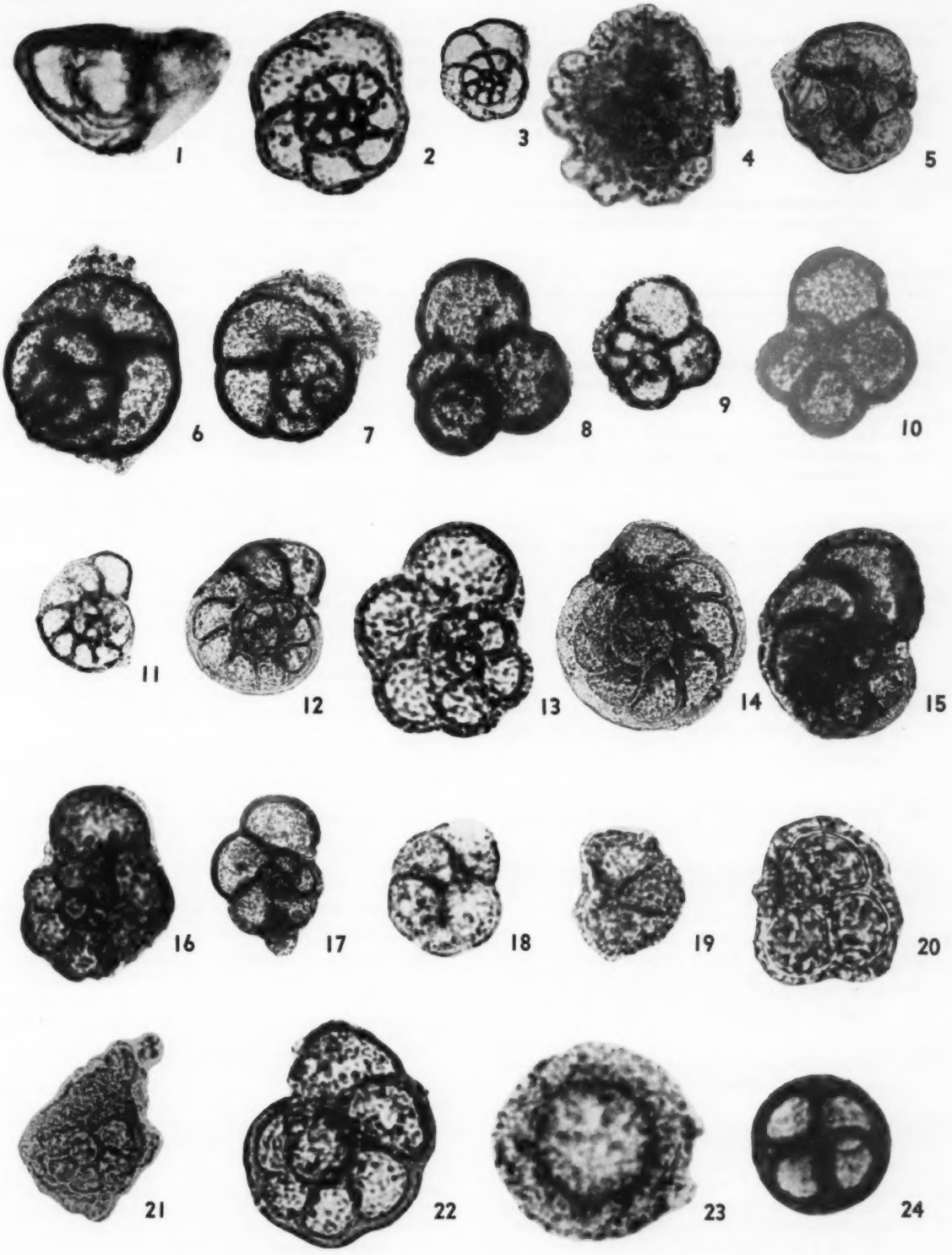
20 Undifferentiated foraminifer
Slide 2 < 200–3, location: 10.5 mm. × 16.3 mm. Focused on the periphery, × 800.

21 Undifferentiated foraminifer (attached)
Slide 1 < 200–2, location: 8.2 mm. × 6.3 mm. Focused on the periphery, × 400.

22 Undifferentiated foraminifer
Slide 1 < 200–4, location: 10.4 mm. × 9.6 mm. Focused on the periphery, × 400.

23 Proloculus(?)
Slide 1 80–200–2, location: 14.9 mm. × 13.7 mm. Focused on the periphery, × 400.

24 Microfossil of uncertain affinity.
Slide 1 < 200–4, location: 8.2 mm. × 15.6 mm. Focused on upper surface.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Note on the Brady Collection of Foraminifera

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The H. B. Brady Collection of Foraminifera includes many specimens described in the classical "Challenger" Report (Brady, 1884), and in several of Brady's earlier publications as listed by Clark (1884). For over 50 years this collection was housed in the University Museum of Zoology, Cambridge, but in 1938 Sir Clive Forster-Cooper and E. Heron-Allen arranged that it should be transferred, on an exchange basis, to the British Museum (Natural History), London. The greater part of the Brady Collection was moved to London in 1939, but owing to the intervention of World War II, the exchange was not completed.

In 1958 it was disclosed that a number of specimens which were regarded in the British Museum as "missing, presumed lost," were still housed in Cambridge. In consequence, the exchange was completed in 1959,when 175 slides and specimens were transferred from Cambridge to London. This post-war instalment includes more than 90 figured specimens, of which 30 are types illustrated in the "Challenger" Report.

The purpose of this note is to publicize the fact that specimens in the Brady Collection, which may have been described as missing during the period 1939–59, may now be available at the British Museum. It is hoped that this statement will help to prevent future taxonomic confusion.

Credit is due to Dr. C. G. Adams, Dr. R. H. Hedley, Dr. C. D. Ovey and Dr. F. R. Parrington who provided information which facilitated the reunion of the two parts of the collection.

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A note on two important collections of foraminifera in the British Museum (Natural History)

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The following well-known collections of foraminifera, which are often thought to be deposited either partly or entirely elsewhere, are, in fact, in this Museum.

THE CHALLENGER COLLECTION OF RECENT FORAMINIFERA

This collection, on which was based H. B. Brady's well-known Challenger Report, was for a long time housed in the Zoological Museum of the University of Cambridge. In 1939 it was transferred in part to this Museum, the transfer being finally completed in 1959. All but a few of the type and figured specimens are now here, but the whereabouts of the rest is unknown. The writer would be pleased to hear from anyone who may know of any of these important slides.

THE ALFRED ISSLER COLLECTION OF JURASSIC FORAMINIFERA

In 1908–9 Issler published in Palaeontographica a paper entitled "Beiträge zur Stratigraphie und Mikrofauna des Lias in Schwaben." Although this material was stated to be deposited in the Geologisches Institut, Tübingen, it was, in fact, sold to the British Museum (Natural History) in January, 1910, by Issler himself and has remained here ever since. The collection comprises 182 slides, all of them strew preparations in Canada Balsam. Preservation is, however, very good and it is easy to identify and examine the figured specimens.

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LIST OF TYPE SPECIMENS DEPOSITED IN THE BRITISH MUSEUM (NATURAL HISTORY) BUT NOT RECORDED AS SUCH IN THE CATALOGUE OF FORAMINIFERA

	Name and Author	Plate and figure number	British Museum (Natural History) Register number
1.	*Alveolina fusiformis* Sowerby, 1850	pl. 9, fig. 5a–b	P 44363
2.	*Carpenteria capitata* Jones and Chapman, 1900	pl. 20, fig. 7	P 22472
3.	*Globigerina conglobata* Brady, 1879	pl. 80, fig. 1	1959.4.13.7
	Globigerina conglobata Brady, 1879	pl. 80, fig. 2	? ZF 1471*
	Globigerina conglobata Brady, 1879	pl. 80, fig. 3	ZF 1470
	Globigerina conglobata Brady, 1879	pl. 80, fig. 4	1957.2.6.1
	Globigerina conglobata Brady, 1879	pl. 80, fig. 5	missing
	Globigerina conglobata Brady, 1879	pl. 82, fig. 5	ZF 1472

* Slide ZF 1471 contains a number of specimens, one of which is supposed to correspond to figure 2.

LIST OF TYPE SPECIMENS DEPOSITED IN THE BRITISH MUSEUM (NATURAL HISTORY) BUT NOT RECORDED AS SUCH IN THE CATALOGUE OF FORAMINIFERA

	Name and Author	Plate and figure number	British Museum (Natural History) Register number
4.	*Nummulina pristina* Brady, 1874	pl. 12, figs. 1–2	P 35413
	Nummulina pristina Brady, 1874	pl. 12, fig. 3	P 35503
	Nummulina pristina Brady, 1874	pl. 12, fig. 4	P 35412
	Nummulina pristina Brady, 1874	pl. 12, fig. 5	P 35504
5.	*Orbitoides (Lepidocyclina) andrewsiana* Jones and Chapman, 1900	pl. 21, fig. 14	P 22447
6.	*Orbitoides (Lepidocyclina) ephippioides* Jones and Chapman, 1900	pl. 20, fig. 9	P 22449
	Orbitoides (Lepidocyclina) ephippioides Jones and Chapman, 1900	pl. 21, fig. 15	P 22444
7.	*Orbitoides (Lepidocyclina) insulaenatalis* Jones and Chapman, 1900	pl. 20, fig. 5	P 22450
	Orbitoides (Lepidocyclina) insulaenatalis Jones and Chapman, 1900	pl. 21, fig. 13	P 22447
8.	*Orbitoides (Lepidocyclina) insulaenatalis* var. *inaequalis* Jones and Chapman, 1900	pl. 21, fig. 12	P 22443
9.	*Orbitoides (Lapidocyclina) murrayana* Jones and Chapman, 1900	pl. 21, fig. 10	P 22440
10.	*Orbitoides (Lepidocyclina) neodispansa* Jones and Chapman, 1900	pl. 20, fig. 3	P 21489
	Orbitoides (Lepidocyclina) neodispansa Jones and Chapman, 1900	pl. 20, fig. 4	P 22448
11.	*Polymorphina lactea* var. *fistulosa* Williamson, 1858	pl. 6, fig. 150	96.8.13.37
12.	*Polytrema miniaceum* (Pallas) var. *involva* Chapman, 1900	pl. 2, fig. 3	03.2.5.90
	Polytrema miniaceum (Pallas) var. *involva* Chapman, 1900	p. 18, text-fig. 2	03.2.5.206
13.	*Vitriwebbina sollasi* Chapman, 1892	pl. 2, figs. 1, 3	P 4719

ISSLER'S JURASSIC MATERIAL

	Name and Author	Plate and figure number	Slide number	British Museum (Natural History) Register number
1.	*Cristellaria arietis* Issler	pl. 5, fig. 255	(35.a)	P 21076
	Cristellaria arietis Issler	pl. 5, fig. 256	(35.b)	P 21075
	Cristellaria arietis Issler	pl. 5, fig. 257	(43.a)	P 21093
	Cristellaria arietis Issler	pl. 5, fig. 258	(35.b)	P 21075
	Cristellaria arietis Issler	pl. 5, fig. 259	(35.b)	P 21075
	Cristellaria arietis Issler	pl. 5, fig. 260	(24.b)	P 21058
2.	*Cristellaria crepidula* (Fichtel and Moll) var. *convoluta* Issler	pl. 5, fig. 261	(69.b)	P 21152
	Cristellaria crepidula (Fichtel and Moll) var. *convoluta* Issler	pl. 5, fig. 262	(64.a)	P 21138
	Cristellaria crepidula (Fichtel and Moll) var. *convoluta* Issler	pl. 5, fig. 263	(90.b)	P 21200
	Cristellaria crepidula (Fichtel and Moll) var. *convoluta* Issler	pl. 5, fig. 264	(63.b)	P 21137
3.	*Cristellaria crepidula* (Fichtel and Moll) var. *striata* Issler	pl. 5, fig. 265	(69.a)	P 21151
	Cristellaria crepidula (Fichtel and Moll) var. *striata* Issler	pl. 6, fig. 266	(69.a)	P 21151
	Cristellaria crepidula (Fichtel and Moll) var. *striata* Issler	pl. 6, fig. 267	(81.a)	P 21178
	Cristellaria crepidula (Fichtel and Moll) var. *striata* Issler	pl. 6, fig. 268	(71)	P 21156
4.	*Dentalina quadrata* Issler	pl. 3, figs. 156–158	(34)	P 21074
5.	*Frondicularia carinata* Burbach var. *longa* Issler	pl. 3, fig. 129	(69.b)	P 21152
6.	*Glandulina biconica* Issler	pl. 2, fig. 64	(51.b)	P 21110
7.	*Marginulina burgundiae* Terquem var. *psilonoti* Issler	pl. 4, fig. 175	(16.a)	P 21042
	Marginulina burgundiae Terquem var. *psilonoti* Issler	pl. 4, fig. 176	(13)	P 21038
8.	*Marginulina quadrilineata* Issler	pl. 4, fig. 185	(58.b)	P 21124
9.	*Ophthalmidium bacularis* Issler	pl. 1, fig. 25	(58.a)	P 21106

ISSLER'S JURASSIC MATERIAL: OSTRACODEN DES LIAS

Name and Author	Plate and figure number	Slide number	British Museum (Natural History) Register number
Bairdia dentata Issler	pl. 7, fig. 341	(81.b)	P 21179
Bairdia dentata Issler	pl. 7, fig. 342	(79.a)	P 21173
Bairdia rostrata Issler	pl. 7, fig. 345	(80.b)	P 21176

ABSTRACT: *The transparent-slide method of thin-sectioning and a method of making photomicrographs are discussed and illustrated.*

Thin-sectioning and photographing smaller foraminifera

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INTRODUCTION

Studies of foraminifera in thin-section have chiefly been restricted to the larger foraminifera. In an article in this journal, Morkhoven (1958) described a simplified and inexpensive method of making oriented thin-sections of matrix-free foraminifera. This method has great application to the study of smaller as well as larger foraminifera, and its importance should not be overlooked.

Studying smaller foraminifera on the basis of internal as well as external morphology offers many advantages.

The more obvious are:

1) Internal morphology helps establish phylogenetic relationships.

2) Internal morphology doubles the data for defining a given taxon.

3) Thin-sections of oriented free specimens greatly help the identification of taxa in rock thin-sections.

The quality of the thin-sections depends on such variables as the skill of the worker, the preservation of the specimen, and the thickness of the sectioned specimen. Quality is attested to by how well the specimen photographs. If the test wall has become recrystallized or if the section is too thick, good photographs are impossible.

THE TRANSPARENT-SLIDE METHOD

The transparent-slide method described by Morkhoven has evidently been known for a number of years. Unfortunately, however, it has not been applied extensively to the study of smaller foraminifera. The writer has modified Morkhoven's original description somewhat. The steps are summarized as follows:

1) The specimen is transferred to the center of a standard petrographic glass slide.

2) A few small pieces of the mounting medium, Lakeside no. 70, are placed around the specimen.

3) The slide is transferred to a small hot plate. The Lakeside is allowed to melt and cover the specimen.

4) From the hot plate the slide is transferred quickly to the stage of a binocular microscope. While the Lakeside is still soft, the specimen is oriented with a fine probe in the position desired for sectioning.

5) The slide is cooled by submerging it in a beaker of water at room temperature. The glass seldom cracks if submergence is swift and complete. Cooling hastens the process considerably.

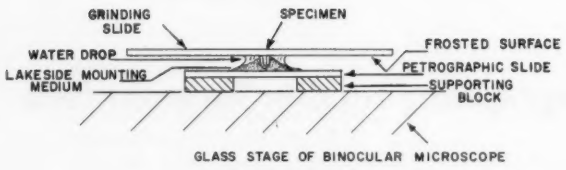
6) The slide is transferred to the stage of the microscope, where it is supported on two small blocks of wood or bottle caps (text-fig. 1).

7) A drop of water is then placed over the specimen and, if need be, a small amount of no. 600 grinding powder is added.

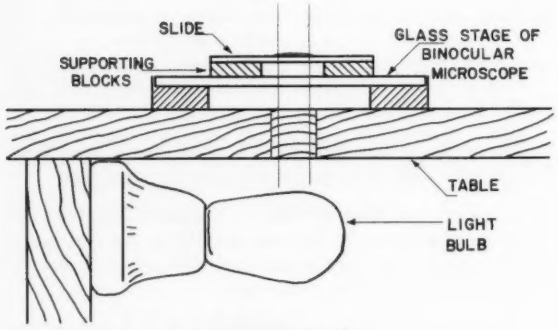
8) A standard biological slide (3″ × 1″) is frosted with grinding powder. For smaller foraminifera with delicate tests, such as *Globorotalia*, the glass slide should be frosted with no. 600 powder. This slide is used as a saw for sectioning the specimen. The water between the grinding slide and the specimen helps to give the worker a "moving-picture" view of the sectioning process (text-fig. 1).

9) When the structure to be illustrated (such as the proloculum) is reached, the slide is reheated and the specimen inverted. Steps 5 through 8 are essentially repeated until the section is of the thickness desired. The required thinness of a sectioned specimen is a matter of experience. If the worker grinds a specimen a fraction of a millimeter too far, all of its features may be obliterated; if a specimen is too thick, it is impossible to photograph. For best results a worker must always keep in mind how well a specimen will photograph.

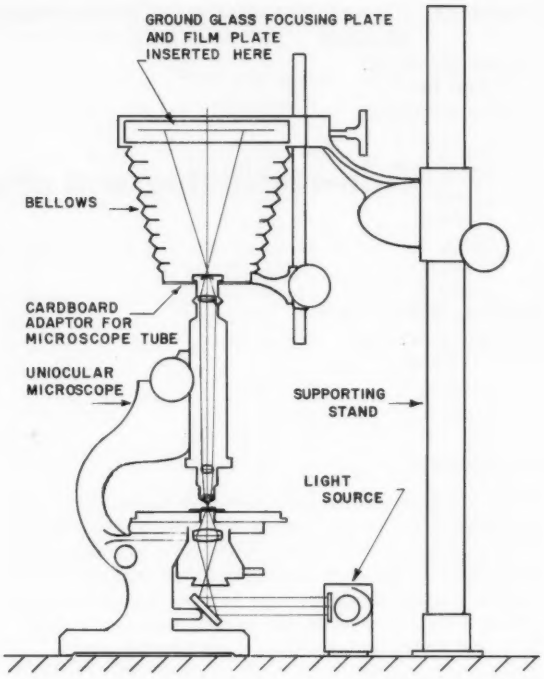
10) A glass cover slip ($^1/_2$″ square) is placed on the hot plate. A relatively large piece of Lakeside is allowed



TEXT-FIGURE 1



TEXT-FIGURE 2



TEXT-FIGURE 3

to melt on the cover slip. The melted Lakeside should just barely cover the cover slip and should be heated until most of its air bubbles have disappeared.

11) The petrographic slide with the sectioned specimen is heated for several seconds on the hot plate. At the same time the cover slip is inverted and placed over the specimen.

12) The slide, with its cover slip, is removed from the hot plate and allowed to cool. Cooling in its last stages can be hastened by repeating step 5.

A few notes can be added. Morkhoven (1958) used Canada Balsam for the mounting medium. The writer, however, has found Lakeside no. 70 to be far superior. It can be heated many times without decomposing or greatly discoloring.

The grinding slide must be kept in good condition. It should be "resharpened" with grinding powder from time to time. One slide can be used almost indefinitely.

Air-filled specimens are not difficult to thin-section. Most air-filled specimens fill with fluid Lakeside during Step 3. Nevertheless, when actual sectioning begins (Step 9), air bubbles are frequently found in the interior once the test wall has been breached. To dispose of air bubbles, Step 3 is repeated.

The final stage of thin-sectioning is carried out with light transmitted from below the microscope stage

PLATE 1

1 *Globorotalia tumida* (Brady)
Vertical section showing calcareous, hyaline, radial, lamellar wall structure. The test is perforate here except for the keel structures which are imperforate; × 306. Recent; Atlantic Ocean.

2 *Globorotalia tumida* (Brady)
Vertical section, × 114. Recent; Atlantic Ocean.

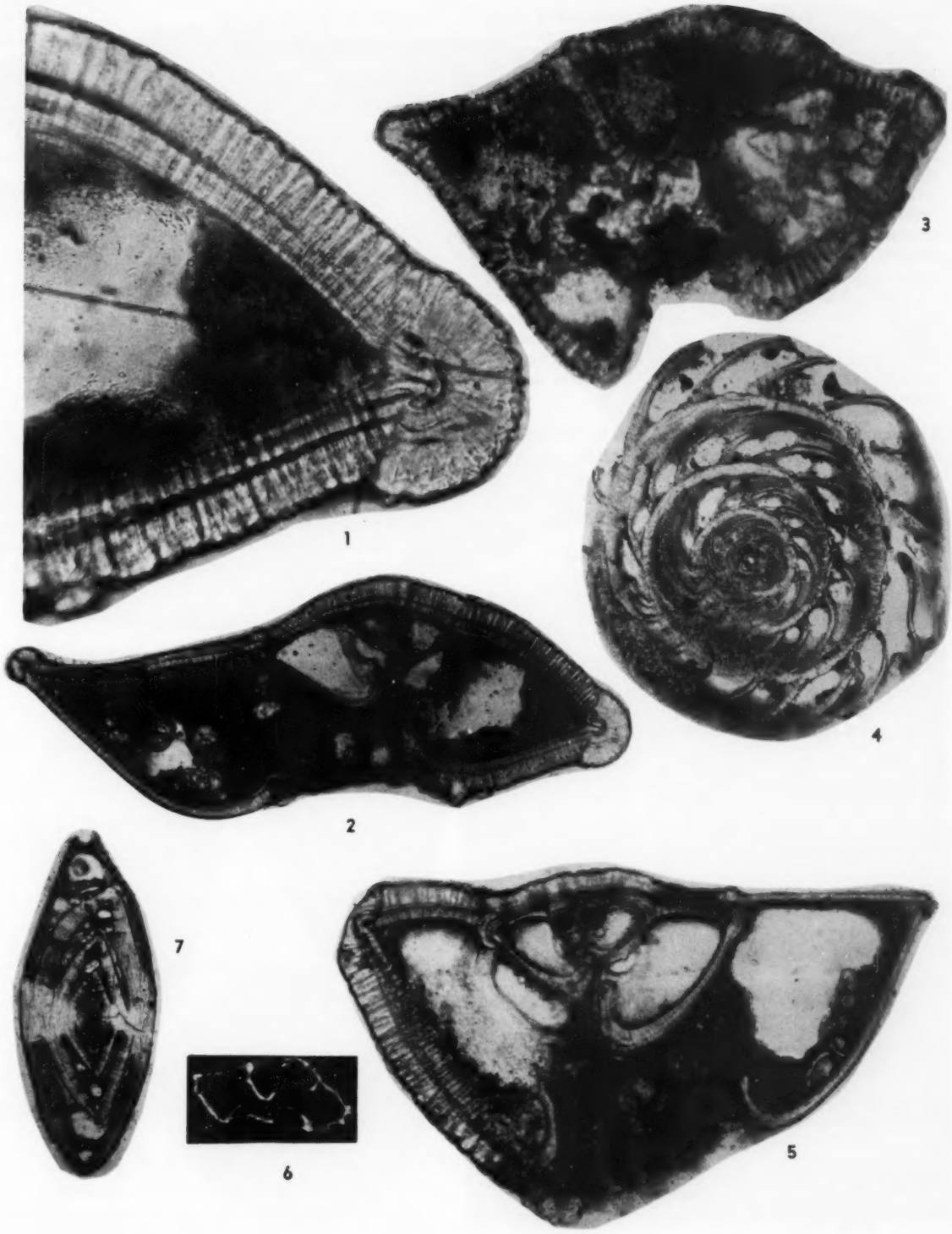
3 *Globorotalia aragonensis* Nuttall
Vertical section, × 214. Eocene; Trinidad.

4 *Amphistegina lessonii* d'Orbigny
Horizontal section, × 55. Recent; Caña Gorda, Puerto Rico.

5 *Globorotalia truncatulinoides* (d'Orbigny)
Vertical section. The outer left keel was chipped in sectioning; × 158. Recent; Atlantic Ocean.

6 *Globotruncana fornicata* Plummer
Vertical section; crossed nicols, × 50. Upper Cretaceous, Puerto Rico.

7 *Amphistegina lessonii* d'Orbigny
Vertical section, × 55. Recent; Caña Gorda, Puerto Rico.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(text-fig. 2). When the section is finished and a cover slip has been added, it can be examined in more detail with a petrographic microscope.

PHOTOGRAPHING THE SPECIMEN

The apparatus used for photography is shown in text-figure 3. A monocular microscope with a good optical system (a petrographic microscope was used by the writer) is placed beneath a bellows apparatus. The bellows is really a graphic camera without a lens; the microscope itself acts as a kind of lens. A cardboard adapter is used between the microscope tube and the bellows. The image from the microscope is projected on a frosted-glass plate at the top of the bellows (text-fig. 3). Although the section under the microscope is in focus before the bellows is lowered over the microscope tube, it must be refocused further on the frosted-glass plate with the fine-focusing mechanism of the microscope.

The image on the frosted-glass plate can be enlarged by raising, or made smaller by lowering, the bellows. Other variables, of course, are the magnification of the microscope lens and ocular used. A lamp with a photoflood bulb serves as the light source to the microscope.

When the picture is to be taken, the frosted-glass plate is removed from the top of the bellows and a film holder with sheet film is inserted. The film is exposed when the lamp is turned on. Exposure time varies with the magnification and the thickness of the thin-section.

A few of the end-products of both the thin-sectioning process and the photographic process are shown in plates 1 and 2. The writer feels that the merits of both of these processes are well substantiated by the illustrations.

ACKNOWLEDGMENTS

The transparent-slide method and various photographic techniques were shown to the writer in 1956 by N. K. Sachs, Department of Geology, Cornell University. The writer is greatly indebted to Mr. Sachs for his help. He is also indebted to the Department of Geology, Princeton University, for the use of dark room facilities.

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Mc Gugan, A.
1959 – *Comments on "A simplified method of grinding foraminifera."* Micropaleontology, vol. 5, no. 1, p. 76.

Myers, E. H.
1943 – *Biology, ecology, and morphogensis of a pelagic foraminifer.* Stanford Univ., Publ. Biol. Sci., vol. 9, no. 1, 30 pp., 4 pls.

Morkhoven, F. P. C. M. van
1958 – *A simplified method of grinding foraminifera.* Micropaleontology, vol. 4, pp. 209–210; fig. 1.

Pessagno, E. A., Jr.
1960 – *Stratigraphy and micropaleontology of the Cretaceous and lower Tertiary of Puerto Rico.* Micropaleontology, vol. 6, no. 1, pp. 87–110, pls. 1–5, text-figs. 1–2.

Wood, A.
1949 – *The structure of the wall of the test in the foraminifera.* Geol. Soc. London, Quart. Jour., vol. 104, pt. 2, pp. 229–255, pls. 13–15.

PLATE 2

1 *Globorotalia menardii* (d'Orbigny) subsp.

Vertical section. This form is similar externally to that pictured by Bolli (1957, p. 266, pl. 29, figs. 7a–b). It is plano-convex and exhibits a more massive wall structure than the typical *Globorotalia menardii*; × 363. Recent; Atlantic Ocean.

2 *Globorotalia menardii* (d'Orbigny)

Vertical section, × 121. This is the typical *Globorotalia menardii*. Recent; Atlantic Ocean.

3 "*Elphidium*" sp. cf. "*E.*" *galvestonense* Kornfeld

Horizontal section, × 74. Recent; Martha's Vineyard.

4 *Lockhartia susuaensis* Pessagno

Paratype; vertical section, × 53. Lower Tertiary of Puerto Rico. Magnifications given by Pessagno (1960) for sectioned specimens of this species are incorrect.

5 *Elphidium macellum* (Fichtel and Moll)

Vertical section, × 73. Recent; Rimini, Italy.

6 *Archaias angulatus* (Fichtel and Moll)

Vertical section showing calcareous, porcellaneous wall structure, × 74. Recent; Caña Gorda, Puerto Rico.

7 *Archaias angulatus* (Fichtel and Moll)

Horizontal section, × 63. Recent; Caña Gorda, Puerto Rico.

8 *Archaias angulatus* (Fichtel and Moll)

Vertical section showing perforate character of the embryonic apparatus. The rest of the test is imperforate; × 378. Recent; Caña Gorda, Puerto Rico.

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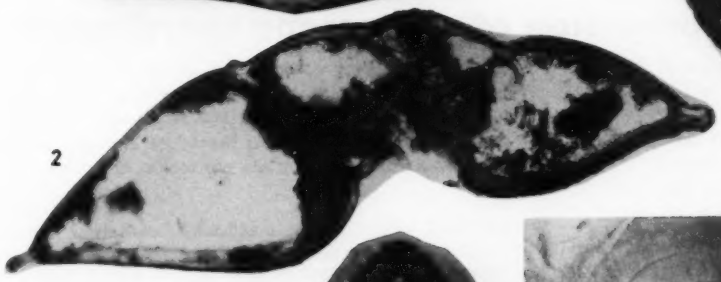
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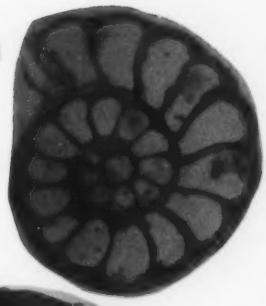
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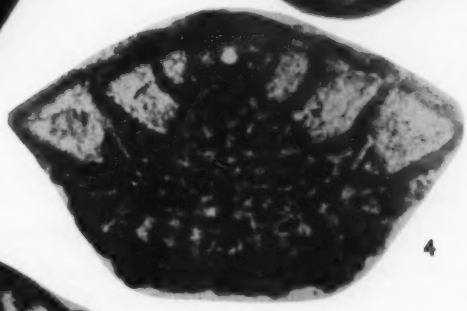
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Still more on conversion of microscope coordinates

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The article in this journal by R. L. Pierce (1959) on conversion of microscope mechanical stage coordinates calls for some additional comment. Pierce notes that the technique I described in 1958 in this journal is "quite usable," and his addition to my technique consists essentially of suggesting that the reference mark on the slide be placed in a position other than in the microscope light path, and of substituting "plus" and "minus" for "up" and "down" in the coordinate citation.

Dr. Pierce states that, in my earlier mention of this technique (1955), I adopted Wodehouse's (1933) technique. This is not exactly true, as I had failed to notice that Wodehouse used such a technique. At the time of the 1958 publication I was not aware of Wodehouse's statement, and my intention was to correct my own 1955 technique, not, as Pierce writes, to criticize Wodehouse's method.

Moreover, it came to my attention as a result of the 1958 note, that K. E. Lohman (1933) published, about the same time as Wodehouse's paper appeared, a technique identical in essentials to the one I outlined in 1958, on which Pierce has now commented. It is regrettable that neither Pierce nor I gave credit to Lohman in our publications, and I am happy to do so now.

In the interest of completeness, R. H. Tschudy (1959, personal communication) has pointed out to me the possibility of constructing a mechanical device, a slide rule, for direct reading of the conversions from one microscope to another. Such a device might be useful where large numbers of readings from one microscope must be converted for use on another instrument. In Tschudy's laboratory, pairs of ordinary millimeter rules, with the scales appropriately marked and placed side by side, are used for this purpose. Microscope stage vernier scales can, however, be read to .1 mm. and estimated to .05 mm., so that it is apparent that arithmetic conversion of stage readings is more accurate than readings from millimeter rules could be. However, a simple, accurate slide rule could be constructed for this purpose, on which the scale is magnified, or for which verniers are provided.

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LOHMAN, K. E.
1933 – *A method for permanently recording the locations of objects on microscope slides.* Science, vol. 78, no. 2019, pp. 214–215.

PIERCE, R. L.
1959 – *Converting coordinates for microscope-stage scales.* Micropaleontology, vol. 5, no. 3, pp. 377–378, table 1.

TRAVERSE, A.
1955 – *Pollen analysis of the Brandon lignite of Vermont.* U. S. Bureau of Mines, Rept. of Investigations 5151, pp. 35–36.
1958 – *Locating plant microfossils on mixed slides.* Micropaleontology, vol. 4, no. 2, pp. 207–208, text-fig. 1.

WODEHOUSE, R. P.
1933 – *Tertiary Pollen. II – The oil shales of the Eocene Green River formation.* Torrey Bot. Club, Bull., vol. 60, p. 483.

ABSTRACT: *One hundred and nine papers on all aspects of micropaleontology are listed and briefly reviewed.*

Annotated bibliography of micropaleontology in Germany for 1959

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This is a continuation of the bibliography published last year in MICROPALEONTOLOGY (1959, vol. 5, no. 4). As before, it is restricted to papers that are concerned with micropaleontology or stratigraphy which mention microscopic fossils. In addition to foraminifera, this bibliography covers ostracodes, radiolaria, and other animal microfossils, as well as microscopic fragments of larger organisms and fossil plant remains. Papers that are important in taxonomy are marked with an asterisk.

ALBERTI, G.

*1959*a* *Über Pseudodeflandrea n. gen. (Dinoflag.) aus dem Mittel-Oligozän von Norddeutschland.* Geol. Staatsinst. Mitt., vol. 28, pp. 91–92, 1 text-fig.
Description of *Pseudodeflandrea gigantea* n. g., n. sp., from the Septarienton of the Golzow well near Potsdam.

*1959*b* *Zur Kenntnis der Gattung Deflandrea Eisenack (Dinoflag.) in der Kreide und im Alttertiär Nord- und Mitteldeutschlands.* Geol. Staatsinst., Mitt., vol. 28, pp. 93–105, pls. 8–9, 1 text-fig.
Description of 14 species of which 11 are new. Four are from the Senonian, three from the lower Eocene, two from the Turonian and one each from the Barrêmian, Aptian, Paleocene, upper Eocene and middle Oligocene.

ANDERSON, H. J.

1959 – *Zur Altersstellung des Tertiärs von Grasbeck bei Walsrode (Niedersachsen).* Neues Jahrb. Geol. Pal., Monatshefte, Pt. B, pp. 205–208.
On the basis of two *Dentalium* species, the glauconitic sands from Grasbeck are given a Miocene age.

BACH, H., HAGENMAYER, P. AND NEUWEILER, F.

*1959 – *Neubeschreibung und Revision einiger Foraminiferenarten und -unterarten aus dem schwäbischen Lias.* Geol. Jahrb., vol. 76, pp. 427–449, pls. 1–2, 2 text-figs.
The descriptions and distribution of eight new species and one new subspecies from the Lias *alpha* 3 to the Lias *gamma* beds are given. The morphology of *Lenticulina (Astacolus) neoradiata* and *Nodosaria reineckei* is discussed.

BACKHAUS, E.

*1959 – *Monographie der cretacischen Thecideidae (Brach.).* Geol. Staatsinst., Mitt., vol. 28, pp. 5–90, 7 pls., 14 text-figs.
A comprehensive study and statistical analysis of the taxonomic characteristics is presented. Twenty-one forms are described including four new species and one new subspecies of the genera *Thecidea*, *Lacazella*, and *Thecidiopsis*, and their vertical range in the Upper Cretaceous is given.

BARTENSTEIN, H.

1959*a* *Die Jura/Kreide-Grenze in Europa. Ein Überblick des derzeitigen Forschungsstandes.* Eclogae Geol. Helv., vol. 52, no. 1, pp. 15–18, 1 text-fig.
A biostratigraphic study comparing beds from southeast France, Switzerland, northwest Germany and southern England. This work is based on data presented in a dissertation by P. Donze (Lyon, 1958).

1959*b* *Die Barrême-Scholle von Mellendorf nördlich Hannover, ehemaliger locus typicus von Roemer 1841, Müller 1893 und Koenen 1902.* Geol. Jahrb., vol. 76, pp. 453–468, 2 pls., 5 text-figs.
Stratigraphically important foraminifera of large isolated glacial blocks of the Lower Cretaceous. A map is included.

1959*c* *Neue mikropaläontologische Beobachtungen zu den Tertiärvorkommen des Reinhardswaldes und des benachbarten Bramwaldes.* Hess. Landesamt Bodenforsch., Notizbl., vol. 87, pp. 367–375, 1 pl., 1 text-fig.
Twelve localities from northern Hesse are described. Upper Oligocene agglutinated foraminifera are indicated as present.

*1959*d* *Feinstratigraphisch wichtige Ostracoden aus dem nordwestdeutschen Valendis.* Pal. Zeitschr., vol. 33, no. 4, pp. 224–242, pls. 27–31, 1 table.
Thirteen new species of *Cytherelloidea*, *Schuleridea*, *Dolocytheridea*, *Euryiticythere*, *Parexophthalmocythere*, *Orthonotacythere*, and *Protocythere* are described. Vertical ranges are also given.

BECKMANN, H.

1959 – *Verunreinigung von Mikroproben beim Schlämmen.* Pal. Zeitschr., vol. 33, no. 1–2, p. 124.
Clean sieves are placed in a solution of methylene blue so that microfossils adhering to the meshes can subsequently be recognized.

BENDER, H.

1959 – *Ein Querprofil durch den Westteil der Hörre und ihre "Phyllite" (Ulmbachtal; Rheinisches Schiefergebirge).* Hess. Landesamt Bodenforsch., Notizbl., vol. 87, pp. 78–88, text-figs. 1–2.
Stratigraphic and bionomic problems, as well as facies problems, of the Upper Devonian and Lower Carboniferous of the Lahn- and Dillmulde are solved through the study of the conodonts.

BERGER, F.

1959 – *Haftmasse zum Photographieren von Mikrofossilien.* Pal. Zeitschr., vol. 33, no. 1–2, pp. 123–124; and Photographie und Wissenschaft, vol. 7, no. 2.
Use and advantages of Agfa-Repro-Haftlack (sticking paste) for mounting purposes.

BETTENSTAEDT, F.

1959 – *Art- und Gattungsbildung. Eine Untersuchung an fossilen Foraminiferen.* Natur und Volk, vol. 89, pp. 367–379, 7 text-figs.
General remarks concerning the investigation of *Gaudryina* and *Spiroplectinata* by B. Gravert (Senckenberg Naturforsch. Ges., Abh. 498, 1959).

BRELIE, G. VON DER

1959 – *Watt-Ablagerungen des Eem-Meeres im Raum von Norderney.* Deutsch. Geol. Ges., Zeitschr., vol. 111, pp. 1–7, 1 text-fig.
The most important diatom species from three shallow wells of the brackish marine "wadden" zone are named.

BROSIUS, M. AND GRAMANN, F.

1958 – *"Heskemer Pollenbild" und Melanienton am Nordrand des Vogelsberges.* Hess. Landesamt Bodenforsch., Notizbl., vol. 89, pp. 162–167, 1 text-fig.
Discussion of sections through the Oligocene Melanienton with a list of the sporomorphs.

1959*a* *Die stratigraphische Reichweite des Heskemer Pollenbildes in Borken (Tertiär, Niederhessen).* Deutsch. Gel. Ges., Zeitschr., vol. 111, pp. 182–197, 3 pls., 7 text-figs.
Vertical range and list of sporomorphs and other microfossils from three complete sections of the lower Rupelton and Melanienton. They show that the association of the so-called "Heskemer Pollenbildes" is always present.
Hystrichosphaerids and peridinids are illustrated.

1959*b* *Das ältere Tertiär von Grossalmerode (Hessische Senke).* Deutsch. Geol. Ges., Zeitschr., vol. 111, pp. 543–558, 4 text-figs., 2 tables.
Lignite seams can safely be correlated by using pollen. A marine bed is dated as lower Rupelton by the foraminifera present.

BUCK, H.

1959 – *Zur Verbreitung der Kieselalgen in den Flußgewässern Nord-Württembergs.* Ver. Vaterl. Naturk. Württemberg, Jahresheft, Jahrg. 114, pp. 96–131. Determination of 264 Recent fresh-water diatoms.

COLOM, G.

*1958 – *Foraminiferen aus dem Kalk von Santa Maria. In: Krejci-Graf, K., Frechen, J., Wetzel, W., and Colom, G.: Gesteine und Fossilien von den Azoren.* Senckenbergiana Lethaea, vol. 39, no. 5–6, pp. 337–347, 4 pls.
Description of 20 planktonic and benthonic foraminifera from Miocene limestones near Pico do Facho.

COOKSON, I. C., AND EISENACK, A.

*1958 – *Microplankton from Australian and New Guinea upper Mesozoic sediments.* Roy. Soc. Victoria, Proc., n. ser., vol. 70, pp. 19–78, pls. 1–12, text-figs. 1–20, tables 1–2.
Description of 75 microfossils, including dinoflagellates and hystrichosphaerids, with 12 new genera and 53 new species from the Jurassic, Cretaceous, and Tertiary.

DAHM, H. D.

1959 – *Diatomeen aus spätglazialen Ablagerungen der Eichholz Niederung bei Heiligenhafen (Holstein).* Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 1, pp. 8–12, 1 text-fig.
Vertical ranges are given diatoms in a 300-meter section (sub-divided into 12 zones) through the late glacial period. Data on past climate are also included.

DEFLANDRE-RIGAUD, M.

*1959 – *Sur quelques sclérites d'Holothurides de l'Oligocène Moyen d'Innien, Holstein.* Rev. Micropal., vol. 1, no. 4, pp. 190–200, pls. 1–3.
Fourteen new species of isolated holothurian remains from the Septarienton of Innien are described.

DENGLER, H.

1959 – *Bisherige Ergebnisse der Anwendung der Conodonten-Chronologie im Devon der Lahnmulde.* Deutsch. Geol. Ges., Zeitschr., vol. 110, p. 627. (Abstract).
Conodonts were used as index fossils in the subdivision of the Devonian and in sections where there are strong facies changes.

EISENACK, A.

*1958 – *Mikroplankton aus dem norddeutschen Apt, nebst einigen Bemerkungen über fossile Dinoflagellaten.* Neues Jahrb. Geol. Pal., Abh., vol. 106, fasc. 3, pp. 383–422, pls. 21–27, text-figs. 1–10.
Ten dinoflagellates with nine new species and 15 hystrichosphaerids with six new species are described from one drill core and one erratic boulder. These species are compared with those from the southern hemisphere.

*1959*a* *Chitinöse Hüllen aus Silur und Jura des Baltikums als Foraminiferen.* Pal. Zeitschr., vol. 33, no. 1–2, pp. 90–95, 1 pl., 1 text-fig.
Chitinous coverings are described under the name *Archaeochitosa*, n. gen., with 3 new species.

*1959*b* *Neotypen baltischer Silur-Chitinozoen und neue Arten.* Neues Jahrb. Geol. Pal., Abh., vol. 108, no. 1, pp. 1–20, pls. 1–3, 4 text-figs.
New descriptions of seven neotypes and of five subspecies of *Conochitina micracantha* are given.

FLÜGEL, H.

*1959 – *Zeapora Penecke 1894: Eine Dasycladaceen-Gattung aus dem Mittel-Devon von Graz.* Neues Jahrb. Geol. Pal., Monatshefte, pp. 145–152, 2 text-figs.
Description of a lectotype and revision of *Zeapora gracilis* which, up to the present, has been considered to be a bryozoan or coral.

FLÜGEL, H., GRÄF, W. AND ZIEGLER, W.

1959 – *Bemerkungen zum Alter der "Hochwipfelschichten" (Karnische Alpen).* Neues Jahrb. Geol. Pal., Monatshefte, pp. 153–167, 2 text-figs.
Rastritis geyeri is a conodont *Polygnathus* species. As a result, the Devonian-Carboniferous boundary can be given in stratigraphic, tectonic, and paleogeographic terms.

FLÜGEL E. AND SY, E.

1959 – *Die Hydrozoen der Trias.* Neues Jahrb. Geol. Pal., Abh., vol. 109, pp. 1–108, 3 pls., 2 text-figs., 3 tables.
A revision and a new classification of diagnostically important Triassic hydrozoans in thin-sections is presented.

GEROCH, S.

1959 – *Stratigraphic significance of arenaceous foraminifera in the Carpathian Flysch.* Pal. Zeitschr., vol. 33, no. 1–2. pp. 113–122, 2 pls., 1 text-fig., 1 chart.
Comparison of a series of beds of different tectonic units. The vertical ranges of 26 species of foraminifera from the Teschener beds are given from the Valanginian to the Hieroglypen-beds of Eocene age. Thin-sections of 11 species and variation statistical analysis of *Hormosina ovulum* are also presented.

GOCHT, H.

*1959 – *Mikroplankton aus dem nordwestdeutschen Neokom (Teil 2).* Pal. Zeitschr., vol. 33, no. 1–2, pp. 50–89, pls. 3–8, 1 tab.
Sixty planktonic species from the Valendis, Hauterivian and Barrêmian have been isolated. They include 10 dinoflagellate and 10 hystrichosphaerid genera with seven new species.

GRABERT, B.

*1959 – *Phylogenetische Untersuchung an Gaudryina und Spiroplectinata (Foram.) besonders aus dem nordwestdeutschen Apt und Alb.* Senckenb. Naturf. Ges., Abh., vol. 498, pp. 1–71, pls. 1–3, text-figs. 1–27, tables 1–3.
Four species each of *Gaudryina* and *Spiroplectinata* are newly described on the basis of variation statistics. Five new species are included in this group. Thirty-seven populations comprising approximately 18,000 specimens were analyzed. These show a gradual alteration of *Gaudryina dividens* from the Aptian to the upper Albian. In this interval, due to further splitting, the genus *Spiroplectinata*, with four new species, is also present.

GRAMANN, F.

1959 – *Das ältere Tertiär der Hessischen Senke.* Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 1, pp. 247 to 248 (abstract).
Biostratigraphic delineation and biofacies of Melanienton, Rupelton and Schleichsand, with special consideration to the foraminifera.

GROHNE, U.

1959 – *Die Bedeutung der Diatomeen zum Erkennen der subfossilen Vegetation Höherer Pflanzen in Marschablagerungen.* Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 1, pp. 13–28, text-figs. 1–5, tables 1–2.
List of diatoms from 11 stations in different brackish water zones in the Elbe Estuary. The diatoms are more extensively subjected to ecologic influences than the phanerogams.

HALLIK, R.

1959 – *Diatomeen als Anzeiger des Sedimenttransportes in der Unterelbe.* Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 1, pp. 29–32, text-figs. 1–2.
Diatoms may lead to an error in the interpretation of the original biocoenoses as they can be easily transported by water.

HARTMANN, G.

*1959 – *Beitrag zur Kenntnis des Nicaragua-Sees unter besonderer Berücksichtigung seiner Ostracoden (mit Beschreibung von 5 neuen Arten).* Zoologischer Anzeiger, vol. 162, pp. 269–294, 9 text-figs.
Ecologic and detailed morphologic data on *Physocypria granadae* n. sp., *Heterocypris nicaraguensis* n. sp., *Potamocypris islagrandensis nicaraguensis*, n. ssp., *Limnocythere royi* n. sp., *Pericythere marginata* and *Cythere* sp.

HELMS, J.

*1959 – *Conodonten aus dem Saalfelder Oberdevon (Thüringen)*. Geologie, vol. 8, no. 6, pp. 634–661, 6 pls., 3 text-figs., 2 tables.
Stratigraphic evaluation and representation of 87 conodonts from 12 horizons. Fifty-nine of these are described including 12 new species and 2 new subspecies.

HILTERMANN, H.

1959*a* *Annotated bibliography of micropaleontology in Germany for 1958*. Micropaleontology, vol. 5, no. 4, pp. 487–496.
One hundred and twenty papers on all aspects of micropaleontology are listed and briefly reviewed.

1959*b* *Stratigraphisch wichtige Foraminiferen der Aachener Kreide*. Pal. Zeitschr., vol. 33, no. 1–2, pp. 9–10 (abstract).
The presence of Santonian, lower Campanian, and lower and upper Maestrichtian beds has been established. Phyletic series, vertically limited species, migrations from the Tethys, and ecologically dependent forms are discussed.

1959*c* *News report – Germany*. Micropaleontology, vol. 5, no. 2, pp. 266–268.
References to various publications, lectures, meetings and excursions.

HINSCH, W., AND MODELL, H.

1959 – *Die Altersstellung des "Obermiozäns" im Raum von Pfungstadt*. Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 1, pp. 168–174, 1 text-fig., 1 table.
Mention of microfossils, mollusks and lithology of drilling sections through a limnic series of 130 meters (Pontian) between the Hydrobien-Schichten and the terrestial Pliocene.

HOFKER, J.

*1959*a* *Orthogenesen von Foraminiferen*. Neues Jahrb. Geol. Pal., Abh., vol. 108, pp. 239–259, text-figs. 1–14.
Theories concerning gradual transitions by means of fossil series of *Bolivinoides*, *Gavelinella*, *Gavelinopsis*, *Neoflabellina* and *Stensiöina* from the Upper Cretaceous.

*1959*b* *Die asterigeriniden Foraminiferen*. Pal. Zeitschr., vol. 33, no. 4, pp. 247–265, text-figs. 1–31.
Morphology of 16 species of *Asterigerina*, *Asterigerinoides*, *Asterigerinata* and *Amphistegina*. *Nuttallides* Finlay is invalid.

HUCKRIEDE, R.

1958 – *Das sogenannte Klesenzafenster in den Vorarlberger Kalkalpen*. Hess. Landesamt Bodenforsch., Notizbl. vol. 87, pp. 227–238, 4 text-figs.
Evaluation of some radiolarians and foraminifera from the Lower Cretaceous.

1959 – *Die Eisenspitze am Kalkalpensüdrand (Lechtaler Alpen, Tirol)*. Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 2, pp. 410–433, 4 text-figs.
Four conodonts from the Anisian are briefly mentioned.

JANKE, J.

1958 – *Sedimente und Mikrofaunen im Bereich der Grenzschwelle zweier ozeanischer Räume, dargestellt an einem Schnitt über den Island-Färöer-Rücken (Nordatlantischer Ozean Rosengarten-Europäisches Nordmeer*. Geol. Rundschau, vol. 47, pp. 234–249, 3 text-figs., 3 tables.
Microlithologic data and some foraminifera from nine stations at a depth of 400 to 1620 meters are discussed.

JOSTEN, K. H.

1959 – *Ein neuer schwach-mariner Horizont in den Oberen Horster Schichten (Westfal. B.)*. Neues Jahrb. Geol. Pal., Monatshefte, pp. 137–139, 1 text-fig.
A thin horizon at the top of the Ägir seam is characterized by the presence of foraminifera and the presence of 0.05% B_2O_3.

KAMPTNER, E.

1959 – *Über die Brauchbarkeit der Parataxia bei Kalkalgen*. Pal. Zeitschr., vol. 33, pp. 5–6 (abstract).
An artificial system is necessary for the isolated remains of coccoliths but not for the Dasycladaceae or nullipores.

KLINGER, W., AND NEUWEILER, F.

*1959 – *Leitende Ostracoden aus dem deutschen Lias β*. Geol. Jahrb., vol. 76, pp. 373–409, 6 pls., 1 text-fig.
Fifteen new species of the sculptured genus *Procytheridea* are described and used for the subdivision of the Lias *beta*.

KLITZSCH, E.

1959 – *Das Mitteldevon am Nordwestrand der Dillmulde. Das Bottenhorner Becken*. Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 2, pp. 366–409, 1 pl., 7 text-figs.
List of some stratigraphically important conodonts.

KOCH, K. E., AND STENGEL-RUTKOWSKI, W.

1959 – *Faziesuntersuchungen in Jura und Unterkreide der westlichen Lechtaler Alpen*. Verh. Geol. Bundesanst., Heft 2, pp. 179–200, 4 text-figs., 1 pl., 1 table.
Calpionellids, *Thalmanninella* and *Hedbergina* from the Lower Cretaceous are used in solving tectonic and paleogeographic problems.

KÖNIG, D.

*1959 – *Diatomeen der Bucht von Arcachon (Dép. Gironde, Frankreich)*. Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 1, pp. 33–61, pls. 1–3, text-figs. 1–4, 5 tables.
Qualitative and quantitative analyses of 210 diatoms including 12 new species collected from 13 stations in the tidal region. Because of higher temperature, there are more species here than in the North Sea.

KRUCKOW, T.

1959 – *Das Miozän der Golfküstenebene von Mexiko.* Neues Jahrb. Geol. Pal., Abh., vol. 109, pp. 130–146, 3 text-figs., 1 table.
Correlation of Miocene sections by means of foraminifera.

KRUTZSCH, W.

*1959*a* *Mikropaläontologische (sporenpaläontologische) Untersuchungen in der Braunkohle des Geiseltales.* Geologie, vol. 8, no. 21–22, pp. 1–425, 49 pls., 38 text-figs., 12 tables.
Comprehensive monographic revision of all palynologic data of the Eocene lignite of the Geiseltal. Taxonomic evaluation of the characteristics. Description, synonymy and illustration of 186 species. Twenty-two genera, 10 subgenera, 167 species, and nine subspecies are given new names.

1959*b* *Einige Fragen der weiteren sporenpaläontologischen Erforschung des Tertiärs der Lausitz (i.w.S.).* Freiberger Forschungshefte, C 50, pp. 42–62, 7 text-figs.
Problems of methods and techniques in palynology.

KRUTZSCH, W., AND LOTSCH, D.

1958 – *Übersicht über die paläogeographische Entwicklung des zentraleuropäischen Alttertiärs (ohne Tethys-Raum).* Geol. Ges., Ber., vol. 3, pp. 99–110, 11 maps.
Paleogeographic maps representing different stages of the Paleocene, Eocene, Oligocene, and Miocene.

KSIAZKIEWICZ, M.

1958 – *Sedimentation in the Carpathian Flysch Sea.* Geol. Rundschau, vol. 47, pp. 418–425, 2 text-figs.
Early Tertiary foraminifera are mentioned.

LESCHIK, G.

1959 – *Sporen aus den "Karru-Sandsteinen" von Norronaub (Südwest-Afrika).* Senckenbergiana Lethaea, vol. 40, no. 1–2, pp. 51–95, pls. 1–5.
Twenty-seven iso- and microspores are described including 15 new species from a *Glossopteris* bed. Assigned to the Lower Permian.

LÜTTIG, G.

*1959 – *Die Ostrakoden des Spätglazials von Tatzmannsdorf (Burgenland).* Pal. Zeitschr., vol. 33, no. 3, pp. 185–197, pls. 1–2, 1 table.
Taxonomy and ecology of six Pleistocene ostracodes of *Cyprinotus, Candona, Erpetocypris* and *Ilyocypris.*

LUTZE, G.

1958 – *Mikropaläontologische Faunenbilder. In:* DORN, P., *Erläuterungen zur Geol. Karte von Bayern 1:25000.* Blatt Gräfenberg.
Vertical distribution of foraminifera and ostracodes from a short section of the Dogger *zeta* and Malm *alpha* of the northern Frankenalb.

MAIER, D.

*1959 – *Planktonuntersuchungen in tertiären und quatären marinen Sedimenten. Ein Beitrag zur Systematik, Stratigraphie und Ökologie der Coccolithophorideen, Dinoflagellaten und Hystrichosphaerideen vom Oligozän bis zum Pleistozän.* Neues Jahrb. Geol. Pal., Abh., vol. 107, pp. 278–340, 7 pls., 4 text-figs., 5 tables.
Description and distribution of six coccoliths, four dinoflagellates, one pterospermopsid and 34 hystrichosphaerids. Twenty new species are described. According to luminescence analysis, the hystrichosphaerids are similar to the radiolarians. Discussion of problems of methods and ecology.

MALZ, H.

*1959 – *Ostracoden-Studien im Dogger, 1: Marslatourella n. g. 2: Fissocythere n. gen.* Senckenbergiana Lethaea, vol. 40, pp. 19–23, 317–331, 2 pls., 5 text-figs.
Marslatourella exposita, n. gen., n. sp., is described from the upper Bathonian of France and southwest Germany. *Fissocythere*, n. gen., with four new species, is described from the *Aspidoides* beds.

MARTIN, G. P. R.

1959 – *Der Typus von Cypridea buxtorfi.* Senckenbergiana Lethaea, vol. 40, p. 316.
Designation of a lectotype.

MARTINI, E.

1959 – *Der stratigraphische Wert von Nanno-Fossilien im nordwestdeutschen Tertiär.* Erdöl und Kohle, vol. 12, pp. 137–140, 1 pl., 1 text-fig.
Methods of utilization of nannofossils and the vertical distribution of 29 species in the Eocene. Description of *Pemma papillatum,* n. sp., from the upper Eocene of California.

*1959 – *Discoasteriden und verwandte Formen im NW-deutschen Eozän (Coccolithophorida) 2. Stratigraphische Auswertung.* Senckenbergiana Lethaea, vol. 40, no. 1–2, pp. 137–157, 6 text-figs.
On the basis of 12 drillings and four exposures, the vertical distribution of 29 nannofossils is given for five horizons from the "lower Eocene 3" to the Neuengammer (Oligocene) gas sand.

MAYNC, W.

*1959 – *Bemerkungen zur Systematik der Lituolidae.* Pal. Zeitschr., vol. 33, no. 4, pp. 199–210.
Discussion of the taxonomic value of different characteristics of the Lituolidae.

MEISL, S.

*1959 – *Eine neue Gaudryina aus dem nordwestdeutschen Eozän (Foram.)* Geol. Jahrb., vol. 76, pp. 411 to 420, 2 pls.
Description of *Gaudryina (Pseudogaudryina) hiltermanni* n. sp. and *trigonalis* n. subsp.

MELLIS, O.

1958 – *Die Sedimentation in der Romanche-Tiefe. Ein Beitrag zur Erklärung der Entstehung des Tiefseesandes im Atlantischen Ozean.* Geol. Rundschau, vol. 47, pp. 218–234, 2 text-figs., 6 tables.
Foraminifera and diatoms mentioned briefly.

MÜLLER, K. J.

*1959*a* *Kambrische Conodonten.* Deutsch. Geol. Ges., Zeitschr., vol. 111, pt. 2, pp. 434–485, 5 pls., 11 text-figs., 3 tables.
Twenty-seven new species of Middle and Upper Cambrian conodonts are described from 40 localities from Europe and North America. The new genera are *Furnishina*, *Hertzina*, *Proacodus* and *Westergaardolina*. The Cambrian-Ordovician boundary is delineated by means of conodonts.

1959*b* *Möglichkeiten und Probleme der Conodonten-Stratigraphie.* Deutsch. Geol. Ges., Zeitschr., vol. 110, pt. 3, pp. 595–597. (Abstract). A means of isolating conodonts from slightly metamorphosed rocks is described.

1959*c* *Nachweis der Pericyclus-Stufe (Unterkarbon) in den Karnischen Alpen.* Neues Jahrb. Geol. Pal., Monatshefte, pp. 90–94.
List of conodonts from two beds. These are comparable with the Lower Carboniferous of Graz.

OERTLI, H. J.

*1959 – *Euryitycythere und Parexophthalmocythere, zwei neue Ostrakoden-Gattungen aus der Unterkreide Westeuropas.* Pal. Zeitschr., vol. 33, no. 4, pp. 241 to 246, 1 pl., 2 text-figs.
Description of two new genera of ostracodes found in the Valendis and Hauterivian of northern Germany, in the Paris Basin and in the Jura Mountains.

PAPP, A., AND THENIUS, E.

1959 – *Tertiär 1. Teil Grundzüge regionaler Stratigraphie.* Handbuch der stratigraphischen Geologie, vol. 3, pt. 1, 411 pp., 89 text-figs., 63 tables.
Biostratigraphic study of sediments from Europe, Africa, Asia and America based on micropaleontology. Palynology is treated by W. Klaus.

PFLUG, H. D.

1959 – *Die Deformationsbilder im Tertiär des rheinisch-saxonischen Feldes.* Freiberger Forschungshefte, C 71, pp. 1–110, 13 text-figs., 5 tables.
Palynology is considered in the discussion of paleogeographic and tectonic problems.

PICARD, K.

1959 – *Gliederung pleistozäner Ablagerungen mit fossilen Böden bei Husum/Nordsee.* Neues Jahrb. Geol. Pal., Monatsheft, 6, pp. 259–272, 4 text-figs.
Pollen diagram of an interglacial peat section analyzed by Dr. Grohne.

POKORNY, V.

*1958 – *Grundzüge der zoologischen Mikropaläontologie.* VEB Deutscher Verlag der Wissenschaften, Berlin, vol. 1, 582 pp., 1 pl., 549 text-figs.; vol. 2, 543 pp., 578 text-figs.
Manual of all stratigraphically important data on the morphology, taxonomy and ecology of the radiolarians, Thecamoebae, foraminifera, tintinnids, chitinozoans, hystrichosphaerids, melanosclerites, scolecodonts, conodonts, ostracodes, otoliths and microfossils Incertae sedis. In addition, the micropaleontologically important fragments of Porifera, Octocorallia, Echinodermata and ascidians are treated. For the first time, the Paleozoic ostracodes are brought into taxonomic relation with the younger ostracodes.

REICHSTEIN, M.

1958 – *Neue stratigraphische Ergebnisse aus der Schichtenfolge vom Unterdevon bis zum Unterkarbon in der Umrandung des Elbingeröder Komplexes (Harz).* Neues Jahrb. Geol. Pal., Monatshefte B, pp. 551–558. Names of some newly discovered conodonts are given.

REYMENT, R.

*1959 – *Zur Fassung der Foraminiferengattung Aragonia.* Pal. Zeitschr., vol. 33, no. 1–2, pp. 108–112, 4 text-figs.
Thin-sections of *Aragonia zelandica* show that the genus is not related to the bolivines.

SCHERP, H.

*1959 – *Foraminiferen aus dem Unteren und Mittleren Zechstein Nordwestdeutschlands, insbesondere der Bohrung Friedrich Heinrich 57 bei Kamp-Lintfort.* Göttingen, Univ., Diss., pp. 1–67, 12 pls., 3 tables.
Vertical range and description of 103 species. Fifty are new species and 16 are new subspecies. They are taken from a 65-meter section from the Niederrhein and from exposures in the southern Harz Mountains.

SCHMIDT, W.

1959 – *Paul William Thomson.* Geol. Jahrb., vol. 75, pp. XI–XXII, Portrait, Bibliography.
Memorial to Thomson, worker in geology, particularly of the Baltic and Niederrhein regions.

STOPPEL, D.

1959 – *Das Oberdevon und Unterkarbon im südlichen Kellerwald.* Hess. Landesamt Bodenforsch., Notizbl., vol. 87, pp. 89–119, 6 text-figs.
Detailed lists of conodonts in southern Kellerwald. Species distribution in four regions representing four different facies is given.

TRIEBEL, E.

*1959*a* *Moenocypris n. g. (Crust., Ostr.).* Senckenbergiana Lethaea, vol. 40, no. 1–2, pp. 1–17, pls. 1–4.

Morphologic details are given for two new species from the upper Oligocene and lower Miocene of the Mainz Basin.

*1959*b* *Zur Kenntnis der Ostracoden-Gattungen Isocypris und Dolerocypris.* Senckenbergiana Biologica, vol. 40, pp. 155–170, 7 pls.
New discoveries and detailed morphologic revisions of Recent freshwater ostracodes *Isocypris beauchampi* and *Dolerocypriss inensis. Dolerocypris madagascarensis* is shifted to the new genus *Tanycypris.*

1959*c* *Eine neue Kamera für mikropaläontologische Aufnahmen.* Leitz Mitt. Wiss. und Technik, vol. 1, pp. 88–89, 2 text-figs.
Description of a camera for photomicrography.

TRIEBEL, E., AND KLINGLER, W.
*1959 – *Neue Ostracoden-Gattungen aus dem deutschen Lias.* Geol. Jahrb., vol. 76, pp. 335–372, 9 pls., 1 text-fig.
New descriptions and vertical ranges of stratigraphically important species of *Aphelocythere, Otocythere* and *Trachycythere* including six new species and two new subspecies.

TRUSHEIM, F.
1959 – *Ergebnisse der Tiefbohrung Groothusen Z 1 bei Emden (Ostfriesland).* Erdöl-Zeitschrift, vol. 7, pp. 273–278, 3 text-figs.
Spores from the coal seams of the Upper Carboniferous are identified by H. Grebe.

VANGEROW, E. F.
1959 – *Eine fossile Erosionsrinne im Kohlenkalk bei Aachen.* Decheniana, vol. 111, pp. 99–101.
Allochthonous foraminifera from the Cretaceous are briefly mentioned.

VOGES, A.
1959*a* *Conodonten aus dem Kulm-Kieselschiefer.* Pal. Zeitschr., vol. 33, no. 1–2, p. 10. (Abstract).
Biostratigraphy of conodonts in the Lower Carboniferous of the Sauerland.

*1959*b* *Conodonten aus dem Unterkarbon I und II (Gattendorfia- und Pericyclus-Stufe) des Sauerlandes.* Pal. Zeitschr., vol. 33, no. 4, pp. 266–314, 3 pls., 5 text-figs., 1 table.
Description of 34 species of the *Gnathodus* elements with three new species. Derived forms of *Pseudopolygnathus prima* are present. First evidence of nine American species in Europe.

VOIGT, E.
1959*a* *Die ökologische Bedeutung der Hartgründe ("Hardgrounds") in der oberen Kreide.* Pal. Zeitschr., vol. 33, no. 3, pp. 129–147, 4 pls., 1 text-fig. (Abstract, vol. 33, no. 1–2, p. 5).
Facies traps caused by boring organisms are widespread and contain accumulated microfossils in excellent preservation.

*1959*b* *Revision der von F. v. Hagenow 1839–1850 aus der Schreibkreide von Rügen veröffentlichten Bryozoen.* Geologie, vol. 8, no. 25, pp. 1–61, 10 pls., 7 text-figs.
One hundred fifty-nine species are critically revised with the help of the original specimens. Forty are figured and newly described. The genus *Bubnoffiella* is new.

*1959*c* *Über Fissuricella n. g. (Bryozoa foss.).* Neues Jahrb. Geol. Pal., Abh., vol. 108, pp. 260–269, 2 pls.
Description of two new species of a uniserial bryozoan.

*1959*d* *Endosacculus moltkiae n. g. n. sp., ein vermutlicher fossiler Ascothoracide (Entomostr.) als Cystenbildner bei der Oktokoralle Moltkia minuta.* Pal. Zeitschr., vol. 33, no. 4, pp. 211–233, 2 pls., 2 text-figs.
Description of a first discovery from the Maestrichtian tuff of the crustacean order Ascothoracida.

WALLISER, O. W.
1959 – *Zum Oberdevon und Unterkarbon von Erdbach-Langenaubach (SW-Dillmulde, Rheinisches Schiefergebirge).* Hess. Landesamt Bodenforsch., Notizbl., vol. 87, pp. 120–132, 1 pl., 3 text-figs.
The stratigraphic and paleogeographic problems of southwest Dillmulde are solved by means of conodonts.

WEHRLI, G.
1958 – *Neue Bearbeitung der Rügenschen Foraminiferen.* Angew. Geol., Zeitschr., vol. 4, p. 345. (Abstract).
All samples from the Upper Cretaceous of Rügen have been substantiated to be lower Maestrichtian.

WEILER, W.
1959*a* *Über Ossiculithen und Otolithen bei Fischen.* Pal. Zeitschr., vol. 33, no. 3, pp. 148–151, 5 text-figs., 1 table.
In addition to otoliths, other irregular aggregations occur in the skinlike labyrinth of fishes.

*1959*b* *Miozäne Fisch-Otolithen aus der Bohrung S. Pablo 2 im Becken von Veracruz in Mexiko.* Neues Jahrb. Geol. Pal., Abh., vol. 109, pp. 147–172, 23 text-figs.
Description of 13 teleosts, including nine new species. Ecologic results are also given.

WICHER, C. A. AND MOOS, B.
*1959 – *Ein Beitrag zur Altersdeutung des Reconcavo, Bahia (Brasilien).* Geol. Jahrb., vol. 77, pp. 35–50, 4 pls.
Assignment of the Ilhas-horizon to the Wealden 5–6 by means of ostracodes. Description of seven Cyprideas, four of which are new. An appendix by B. Moos describes five species of *Cypridea,* two of which are new.

WETZEL, W.

1958*a* *Mikropaläontologie im Dienste der Vorgeschichtsforschung.* Mikroskopie, vol. 12, pp. 408–410, 2 text-figs.
Age determination of two small flint artifacts by means of hystrichosphaerids.

1958*b* *Graptolithen und ihre fraglichen Verwandten im elektronenmikroskopischen Vergleich.* Neues Jahrb. Geol. Pal., Monatshefte, pp. 307–312, 3 text-figs.
Discussion of the minute structures of *Diplograptus* and *Rhabdopleura* examined under an electron microscope.

1959 – *Das lumineszenzmikroskopische Verhalten von Sedimenten.* Neues Jahrb. Geol. Pal., Abh., vol. 107, pp. 261–277, 3 pls.
Short notes on the luminescence analyses of hystrichosphaerids, sporomorphs, foraminifera and others.

WOLBRUG, J.

*1959 – *Die Cyprideen des NW-deutschen Wealden.* Senckenbergiana Letheae, vol. 40, pp. 223 to 315, 5 pls., 27 text-figs.
All species of *Cypridea* occurring at the Jurassic-Cretaceous boundary are mentioned. Detailed description of 33 species with eight new species and six new subspecies. Stratigraphic and phylogenetic relations are given.

ZEDLER, B.

1959 – *Zur Stratigraphie des Ober-Hauterive im Erdölfeld Georgsdorf (Emsland).* Erdöl und Kohle, vol. 11, pp. 879–883, 1 text-fig., 1 table.
Stratigraphic range and frequency of 20 foraminifera species in a 194-meter section of the upper Hauterivian.

ZEIL, W.

1958 – *Sedimentation in der Magallanes-Geosynklinale mit besonderer Berücksichtigung des Flysch.* Geol. Rundschau, vol. 47, pp. 425–443, 16 text-figs.
Foraminifera briefly mentioned.

ZIEGLER, F. H.

*1959*a* *Lituola grandis (Reuss) aus dem Untermaastricht der Bayerischen Alpen. Ein Beitrag zur Systematik und Stammesgeschichte der Lituolidae (Foram.).* Palaeontographica, vol. 112, pt. A, pp. 59 to 132, 5 pls., 3 text-figs.
Taxonomic revision and detailed description of *Spirolina grandis* Reuss, 1854, on the basis of 8,000 specimens, most of which were obtained from Gerhardsreut, Siegsdorf and Starzmühle. A neotype is established. A discussion on the importance of different characteristics, some of them represented by statistical methods, is included. Also included is a discussion on the development of secondary wall structures by pyritization, and a key to the genera of the Lituolidae.

*1959*b* *Mikropaläontologische Untersuchungen zur Stratigraphie des Braunjura in Nordbayern.* Geologica Bavarica, pp. 9–128, 5 pls., 1 text-fig., tables.
Distribution of 175 foraminifera and 12 ostracodes in central and northern Frankenalb. Subdivision of the Bajocian into six horizons, the Bathonian into two horizons and the Callovian into three horizons. Description of 11 new species and one new subspecies of foraminifera.

ZIEGLER, W.

*1958 – *Conodontenfeinstratigraphische Untersuchungen an der Grenze Mitteldevon/Oberdevon und in der Adorfstufe.* Hess. Landesamt Bodenforsch., Notizbl., vol. 87, pp. 7–77, 12 pls., 7 text-figs., 10 tables.
Conodont stratigraphy in the Rheinische Schiefergebirge on the basis of sections in Marienberg, Wildungen and Sessacker. Tables of vertical ranges of the known forms are distributed among 12 genera including *Gnamptognathus*, n. gen. Description and illustration of 42 species, 12 of which have been given new names.

1959*a* *Conodonten aus Devon und Karbon Südwesteuropas und Bemerkungen zur bretonischen Faltung.* Neues Jahrb. Geol. Pal., Monatshefte, pp. 289–309, 3 text-figs., 2 tables.
Systematic investigations of conodonts from sections of Montagne Noire, Mouthoumet, Isobol (Segre-valley), Cerri (Pallaresa-valley), and the Canal-Roya-valley (Aragon). They prove that there is a Tournaisian and a Devonian section without hiatus. Fifty-one species and subspecies from the Upper Devonian and 32 from the Lower Carboniferous are listed in tables.

*1959*b* *Ancyrolepis n. g. (Conodonta) aus dem höchsten Teil der Manticoceras-Stufe.* Neues Jahrb. Geol. Pal., Abh., vol. 108, pp. 75–80, 1 pl.
Ancyrolepis cruciformis n. gen., n. sp., from the Upper Devonian cephalopod limestones of the Dillmulde is described as a short-lived form.

news reports

CANADA

FRANK L. STAPLIN

This news report, the first to appear from Canada, is undoubtedly incomplete. Micropaleontologists not contacted should send reports to this correspondent at Imperial Oil Limited, 339–50th Avenue S. E., Calgary, Alberta.

Geological Survey of Canada (Ottawa)

Palynological studies are being conducted by P. A. Hacquebard, D. C. McGregor, and J. Terasmae. Both Pleistocene and pre-Pleistocene palynological laboratories have been established in the new Geological Survey of Canada building.

P. A. Hacquebard's work on spores of Upper Carboniferous strata in the Mabou coal area of Nova Scotia will be published shortly by the Nova Scotia Department of Mines and the Nova Scotia Research Foundation in the report of the Third Conference on the Origin and Constitution of Coal (1956). P. A. Hacquebard, M. S. Barss, and J. R. Donaldson will publish a paper on the distribution and stratigraphic significance of small spore genera in the Upper Carboniferous of the Maritime Provinces, in the Compte Rendu of the Fourth Carboniferous Congress, Heerlen. Spore studies are continuing on the coal seams of the Joggins, Pictou, and Springhill coalfields of Nova Scotia, on the Pennsylvanian strata of New Brunswick, and on subsurface rocks of Prince Edward Island.

D. C. McGregor is engaged in a long-term study of small spores of Devonian age. A paper involving several species of Devonian spores with proximal radial structures is in preparation. Two papers will report on Lower Devonian spore assemblages of the Sextant formation (James Bay Lowland, Ontario) and of the Battery Point formation (Gaspe sandstone, Quebec). His study of Devonian spores from Melville Island in the Canadian Arctic Archipelago will be published shortly in Palaeontology. During 1959 he prepared the guidebook and led the paleobotanical excursion to Gaspé and the Maritime Provinces under the auspices of the IX International Botanical Congress, Montréal, Quebec.

J. Terasmae is continuing research on the palynology of Pleistocene and Tertiary deposits from eastern Canada and the Arctic. Papers are being prepared dealing with palynological studies of deep cores (Pleistocene, Hamilton, Ontario). Palynological studies of varved clays and other "laminated" deposits are being made in order to determine their mode of deposition. He acted as subleader for two trips of the IX International Botanical Congress.

M. J. Copeland is presently studying Upper Silurian ostracode faunas of Eastern Canada. A paper on ostracodes of the Stonehouse formation, Arisaig, Nova Scotia, will appear in Palaeontology. This fauna agrees closely with that of the "*Beyrichiakalk*" of the Baltic region of Europe. Work continues on faunas of similar age from Nova Scotia, New Brunswick, and Quebec. He is also continuing work on Jurassic ostracode faunas from the subsurface of the Canadian Western Plains and outcrops of the Rocky Mountain Foothills. Two short papers are near completion; one on a Kinderhook microfauna from Crowsnest Pass, Alberta, and the other on a large leperditid ostracode from the Arctic.

R. T. D. Wickenden, paleontologist, working on the foraminifera at the Western Plains office of the Geological Survey Canada, Calgary, has recently gone to Dehra Dun, India, under the auspices of the International Economic and Technical Cooperation Division of the Department of Trade and Commerce. He is associated there with the Indian Oil and Natural Gas Commission.

Geological Survey of Canada micropaleontologists welcome the exchange of small spores and ostracodes and samples with colleagues elsewhere. These will be placed in the index files of the Geological Survey for comparative purposes.

Research Council of Alberta (Edmonton, Alta.)

The micropaleontological group is loosely divided into two sections. Robert Green, head of the geological division, is in charge of Paleozoic material, while J. H. Wall directs Mesozoic studies. Dr. Green reports abundant silicified ostracodes from the Banff formation (Kinderhook-Osage), Alberta. Many species have close affinities with those from the Mississippi Valley section. He is also working on late- and postglacial ostracodes of Alberta, which are being used in conjunction with molluscan faunas to interpret paleoecological conditions during the late stages of deglaciation in Alberta.

Miss W. MacKay is studying endothyroid foraminifera from the Rundle type section, as well as from the Pekisko, Shunda and Turner Valley beds of the Bow Valley (all Mississippian). The project will be submitted as a M. Sc. thesis at the University of Alberta. Dr. Wall is working on Upper Cretaceous microfaunas of the Wapiabi and Blackstone formations of the Alberta Foothills. He is also preparing a paper on the foraminifera of the Bad Heart sand section (Smoky River area, Alberta). He hopes to publish soon his work on Jurassic microfaunas of Saskatchewan (Ph. D. Thesis, University of Missouri, 1958). Approximately 100 foraminiferal and 35 ostracode species of the Shaunavon and Vanguard formations are included. J. D. Campbell is working on the paleobotany and palynology of Upper Cretaceous-lower Tertiary deposits of Alberta. He is also working on fossil woods of all ages and would like to obtain specimens for research purposes.

British Columbia University (Vancouver, B.C.)

G. E. Rouse is working on plant microfossils from the Cretaceous and early Tertiary of the Vancouver area, and is investigating paleoecological patterns of various sedimentary basins in British Columbia. He led the West Coast paleobotanical field trip of the IX International Botanical Congress. Laboratory facilities are being expanded to handle increased student interest in palynology. G. Kiss is undertaking pollen analysis of a peat deposit in Vancouver that may yield a complete immediate post-glacial to Recent sequence.

McMaster University (Hamilton, Ont.)

Prof. N. W. Radforth reports the following work in progress in Palynology and Micropaleobotany. The establishment of morpho-physiological trends revealed in comparative and sometimes ontogenetic Paleozoic and Mesozoic microfossil complexes. The evidence for habitat in the Paleozoic as revealed by macro-microfossil *in situ* relationships. Microanalysis of northern Ontario lignite. Microanalysis of peats, especially pollen and cuticle studies. Papers in press include: The significance of plant microfossils found in Canadian Devonian rocks; Definitive microfossils pertinent to physiographic differences in muskeg; Paleobotanical analysis of selected fossil plants from the Minto coal beds of New Brunswick; Paleobotanical field investigations in Eastern Canada (edited joint summary, IX International Botanical Congress paleobotanical field trip).

University of Saskatchewan (Saskatoon, Sask.)

Dr. Margaret Steeves, research associate, is directing investigations in the palynology of Mesozoic sediments. The project only started in September, 1959, but, according to a University press release, is well-advanced. She is anxious to obtain graduate students interested in spore and pollen work.

Micropaleontological consultants

A. McGugan of Calgary (recent lecturer in Geology and Paleontology, Queen's University, Ontario) will report on Upper Cretaceous foraminifera of Vancouver Island at the Paleontological Society of America meetings, Vancouver.

Over 120 species have been recognized, including many open marine species of stratigraphic importance. A significant faunal break marks the Campanian-Maestrichtian boundary. A recent paper with Miss J. E. Rapson described the stratigraphy of the Norquay formation, Banff area, and reported Lower-Middle Pennsylvanian fusulinids from the section (Jour. Alberta Soc. Petrol. Geol., vol. 8, no. 1, 1960).

Imperial Oil Limited (Calgary, Alta.)

J. Jansonius is investigating the spore-pollen assemblages of Permian and Triassic age in Western Canada. Hystrichospherids are common in marine phases. Because of the incomplete section and the scarcity of literature, it is difficult to evaluate whether differences in detail from European and Gondwana assemblages reflect age or facies. The study will be incorporated in a doctoral thesis. He would like to receive fresh shale, marl or coal samples (10–15 gm.) from the Permian-Triassic deposits of any area. Exchanges can be arranged for Upper Jurassic-Lower Cretaceous, Upper Mississippian, and possibly other material. Address c/o Imperial Oil Limited, 339–50th Avenue S. E., Calgary.

S. A. Pocock is completing a paper on the palynology and stratigraphy of the Upper Jurassic-Lower Cretaceous boundary sediments of Western Canada and their correlation with the European section. Preliminary results were presented during the meetings in Pittsburgh of the Geological Society of America. Many new species are included. With C. H. Crickmay, he will present a paper on the paleontology and stratigraphy, including palynology, of the Upper Cretaceous deposits of Vancouver and Vancouver Island at the Cordilleran section meetings, to be held in Vancouver, May, 1960. P. C. McGill presented a paper on Lower Cretaceous foraminifera and ostracodes from the Anderson River area, Northwest Territories, during the First International Symposium on Arctic Geology, held in Calgary, January, 1960. Miss D. M. Loranger is presently in England engaged in advanced studies in micropaleontology and paleoecology. F. L. Staplin is continuing studies on Devonian and Mississippian spores from Western Canada. A portion of the work, entitled Upper Mississippian plant spores from the Golata formation, Alberta, Canada, will be published in Palaeontographica, Abt. B., during 1960 (nine new form genera, 85 new species). He is preparing notes on a Mississippian verrucose species of *Torispora* and on Devonian hystrichospherids and Chitinozoa. In connection with stratigraphic work on the Mississippian-Pennsylvanian boundary by H. L. Halbertsma, he is working on various assemblages. One, from the Lower Tyler shale of Montana, is similar to the assemblage described from pre-Belden beds of Utah by M. P. Schemel in the Journal of Paleontology in 1950. Some preliminary results were presented at the AAPG regional meeting, Billings, Montana. A note by the staff on

palynological techniques will be published in Micropaleontology. A joint paper by Staplin, Pocock and Jansonius, discussing uses of hystrichospherids in Western Canada, will be presented at the AAPG-ASPG Frontiers of Exploration conferences, Banff, Alberta, May, 1960.

Recent visitors included Dr. R. Potonié of the Geologisches Landesamt, Krefeld.

Shell Oil Company, Limited (Calgary, Alta.)

Palynological studies conducted by A. P. Audretsch will soon supplement other paleontological work at Calgary.

The Texas Company (Calgary, Alta.)

Karl O. Parsch will soon begin studies on Mesozoic foraminifera of Western Canada. A graduate of Stuttgart, he has published on marine worms and Jurassic serpulids.

FRANK L. STAPLIN
Imperial Oil Company, Limited
Calgary

NEW ZEALAND

N. DE B. HORNIBROOK

The New Zealand Geological Survey, with headquarters at Lower Hutt City, is currently working on the production of a 4-mile to one inch geological map of the entire country. The Micropaleontology Section is busy coping with its share of the paleontological part of this program.

George Scott is working on the foraminifera of the type Otaian (upper Oligocene-lower Miocene) section at Bluecliffs and will produce an illustrated microfaunal monograph. As a contribution towards the question of the environment of banded sediments, he has studied samples systematically collected from an outcrop of upper Miocene alternating graded strata, in terms of stability of the microfauna and size-frequency distribution of *Uvigerina miozea*. Specific composition of the fauna shows little change from bed to bed but relative abundance of some groups varies widely. Size-frequency distributions of *Uvigerina miozea* may indicate a little-modified life assemblage. The results of this isolated study, at least, are not in accordance with the currently popular theory of redeposition of banded graded sediments.

S. G. Hulme has been working on an improved mechanized technique for processing foraminiferal samples and has developed a motor-driven unit which incorporates a moulded soft rubber head on a spindle, rotating against a soft diaphragm of sheet rubber, held in a metal cylinder. The washing apparatus consists of a metal cylinder with two high pressure water jets, one maintaining turbulence, the other directed against a 200-mesh gauze window. Details of this equipment will be published shortly.

Dr. W. F. Harris is continuing his work on New Zealand post-Miocene pollen and spores with special emphasis on the Plio-Pleistocene boundary and on a more detailed subdivision of late glacial and post-glacial sequences. David McIntyre has recently joined the Palynology Section and is starting work on Tertiary pollen.

Your correspondent has completed Part 1 of his study of the sequence of Eocene to lower Miocene foraminifera in Oamaru District which should appear later this year as Paleontological Bulletin 34 of the New Zealand Geological Survey.

Shell B. P. and Todd Oil Services Ltd., drilled a deep well in Taranaki last year and struck gas. They expect to drill another well this year. Dr. M. Geiger, who has been working on the smaller foraminifera of Taranaki for the past two and one-half years, has returned to The Hague and is to be replaced.

B. P. Shell and Todd Petroleum Development, Ltd., are continuing their exploratory work in the Gisborne – East Coast District and began drilling their first well in April. Mr. F. C. Dilley, who spent a year in New Zealand working on smaller foraminifera, has returned to Sunbury and has been replaced by Dr. Graham Jenkins.

At Victoria University of Wellington, Paul Vella is working on lineages of *Uvigerina* and believes that they have considerable stratigraphic value and illustrate some fundamental aspects of foraminiferal taxonomy.

At the New Zealand Oceanographical Institute in Wellington, S. Kustanowich is starting work on New Zealand Recent foraminifera.

N. DE B. HORNIBROOK
Geological Survey of New Zealand
Wellington

SPAIN

GUILLERMO COLOM

J. Bauza, a Majorcan paleontologist, has been working in recent years on the otoliths of living and fossil fishes. His fossil material is chiefly from Miocene marly sediments of the Iberian Peninsula and Majorca. This material is much richer in otoliths than in teeth and skeleton fragments and is a source of many

species unknown in the Miocene and Pliocene seas of Spain. Dr. Bauza has recently published many papers on otoliths in various Spanish journals.

According to an interesting note by Menendez and Florschütz *(Algunas noticias sobre el ambiente en que vivió el hombre durante el gran interglacial en dos zonas de ambas Castillas.* Estudios Geológicos, vol. 15, nos. 41–44, 1959, pp. 277–282, pls. 40–42). Acheulian man, as found at Villaverde (Madrid), lived in an area of grassy plains and pine groves. Palynological analyses reveal a higher percentage of non-arboreal than arboreal pollen. The region during the Mindel-Riss interglacial would then have been one of prairies with isolated pine groves.

Other recent joint papers by these authors are: *Un fenómeno periglacial en Asturias y algunas consideraciones y deducciones relativas a la formación y datación palinológica de suelos (avec un abrégé en français).* R. Soc. Esp. Hist. Nat., Bull., 1959, vol. 57, pp. 133 to 140, pl. 1, and *Contribución al conocimiento de la historia de la vegetación en España durante el Cuaternario.* Acta V. Congr. Asoc. Intern. Estudio del Cuaternario, 1957 (in press).

Your correspondent has described a new genus of the Ophthalmidiidae, *Gymnesina glomerosa*, living off the Balearic Islands and the Mediterranean coasts of the Iberian Peninsula. This species was found in depths from 50 to 200 meters on an arenaceous substratum which contains abundant calcareous detritus. Its small white calcareous test, with one or more apertures, is covered with large shell fragments and sand which almost completely conceal it, so that it can easily pass unnoticed (Cush. Found. Foram. Res., Contr., vol. 10, pt. 1, 1959, pp. 16–19, pl. 4, 5). A new species of *Hofkerina* was also found (Revue de Micropaleontologie, no. 3, 1958, pp. 148 – 154).

A new species of *Colomiella* Bonet has been found in North Africa (J. Bolze, G. Colom and J. Sigal, Revue de Micropaleontologie, no. 1, 1959, pp. 50 to 52, pl. 1) in Barremian (Lower Cretaceous) beds. This genus of fossil tintinnids was known only from Mexico; its geographic area now extends through the Tethys seas to the Mediterranean.

In Colom, "Notas micropaleontológicas y ecológicas sobre algunas formaciones continentales españolas" (Estudios Geológicos, vol. 15, nor. 41–44, 1959, pp. 93–106) an account is given of different complex associations of fresh and brackish water organisms: oogonia of Characeae, ostracodes, micromollusks, foraminifera and others. A most unexpected find was that of a tropical foraminifer, *Discorinopsis aguayoi* (Bermudez) in the strata of a fossil peat bog, probably Calabrian in age, at Torreblanca (Seville). Its tests are very hyaline, slightly calcified, and often broken because of their fragility. However, good samples were obtained which fully confirmed the identification of this species. In Bermudez' original description, the species is cited as essentially marine, but later, Drs. Cushman and Bronnimann found it living in a mangrove swamp on the island of Trinidad (T.W.I.). It does not appear to exist in the Mediterranean today. The only other citation of this fossil in the Mediterranean region is from the Calabrian of Sicily (Giunta Ilacqua, 1956). In both cases, it would belong to the cold period of the lower Quaternary and was possibly already in a phase of disappearance from our latitudes.

In a paper entitled "*Sobre una nueva concepción de la sedimentación geosinclinal*" (Las Ciencias, Madrid, año 24, no. 1, pp. 85–91, 1959), G. Colom indicates that, according to our present knowledge, the purely pelagic facies of the Upper Jurassic and Lower Cretaceous in the geosynclines of the Sierras of southern Spain and of the Balearic Islands are not very thick (from less than 50 meters to a maximum of 300 meters). Therefore, the author accepts R. Trümpy's term "leptogeosynclines" for these bathyal zones in which such thin deposits accumulated in spite of the length of time that they represent: Upper Jurassic to the very high Lower Cretaceous (Barremian – Aptian), in different localities. An accumulation of great quantities of sediments, corresponding to Hall and Dana's classic theory of the geosyncline as representing "a long and continuous subsidence", apparently did not take place in the Betic-Balearic geosynclines.

For the past two years J. M. Olivares, B. Escandell and G. Colom have been studying the Tertiary lignites of the island of Majorca. Field studies and the examination of 42 borings show that the lignites were formed in lakes that were entirely freshwater, with no brackish influences, and occur in three stages: Upper Ludian, Sannoisian and Stampian. In their thinnest beds the existence of varves with diatoms (chiefly chainlike forms of *Melosira, Cyclotella, Cymbella*) has made it possible to reconstruct the seasonal phases of the lakes.

These lake-bottom diatom-bearing sediments contain precipitates of iron and magnesium compounds, causing the formation of excellent varves separated by fractions of $^1/_{15}$ to $^1/_5$ mm.

Fine limestone beds, corresponding to shallower biotopes, or to periods of sharp subsidence within them giving rise to shallow-water deposits have yielded numerous remains of the encrusting Cyanophyceae preserved in clearly outlined calcite molds from which it has been possible to recognize various genera of the living association *Schizothricetum.* Vestiges of *Chaetophora* occur less frequently.

Fields of Characeae were also present in these biotopes, especially in shallow water areas. The oogonia of different species have been collected. Two species are typical of these formations: *Harrisichara tuberculata* (Lyell) Grambast, characterising Sannoisian levels, and *Rhabdochara langeri* (Hetting) characterising higher, Aquitanian levels that do not contain coal (Publications Inst. Geologico y Minero de España, in press.)

Papers by French geologists and micropaleontologists have been published on local geology of Spain. The stratigraphy in these is based chiefly on foraminifera.

GUILLERMO COLOM
Soller, Majorca

UNITED STATES-EAST-CENTRAL REGION

ROBERT V. KESLING

Indiana Geological Survey

Dr. G. K. Guennel has the following projects in progress at the Survey: Palynology of coals of two cores from the Dicksburg Hills and Merom Bluff areas; Palynology of the coals in the Mansfield formation; Palynology of the coals in Parke County, especially those associated with the Paper Coal outcrops; Reconstruction of the vegetation of the Paper Coal; Origin, deposition, and composition of the Indiana Paper Coal; and a taxonomic problem on *Torispora* vs. *Bicoloria*.

He also contemplates studies on macrospore palynology of the Pottsville coals and the palynology of the Conemaugh coals of Indiana.

Dr. R. H. Shaver has been busy with parts of the Treatise volume on Ostracoda. With Dr. M. L. Thompson, he is continuing studies of Lower Pennsylvanian fusulinids and ostracodes, mostly from Indiana. He also has a paper in press in the Journal of Paleontology on *Bairdia oklahomaensis*.

Indiana University

Dr. D. E. Hattin is completing his study of arenaceous foraminifera from the Waldron Shale (Middle Silurian) of Indiana. The fauna includes over 40 species which are assigned to 18 genera. He will discuss this work in a paper before the annual meeting of the Southeastern Section of the Geological Society of America in Lexington in March, 1960.

Mr. John Utgaard, a graduate student majoring in paleontology at Indiana University, and Dr. T. G. Perry are completing a joint study of the fenestrate bryozoan fauna (exclusive of *Archimedes*) of the Glen Dean limestone (middle Chester) of Indiana. Results of this study will be presented by Mr. Utgaard at the annual meeting of the Southeastern Section of the Geological Society of America at Lexington in March, 1960.

Professor T. G. Perry has recently initiated a study of Middle Ordovician bryozoans of pre-Spechts Ferry age in northwestern Illinois and adjacent parts of Iowa and Wisconsin. He has very recently submitted a manuscript dealing with the Spechts Ferry bryozoan fauna of this area for publication by the Illinois Geological Survey.

In January, 1960, Dr. J. J. Galloway and G. M. Ehlers (University of Michigan) published a paper on "Some Middle Devonian stromatoporoids from Michigan and southwestern Ontario, including the types described by Alexander Winchell and A. W. Grabau," Univ. Mich., Contrib. Mus. Paleontology, vol. 15, no. 4, pp. 39–120, 13 pls.

Illinois Geological Survey

Palynological investigations at Illinois continue to progress along several fronts. Miss Kathy Schaeffer is completing her doctorate thesis concerned with the morphology and taxonomy of bisaccate pollen grains of Lower Permian deposits from southwestern United States. She is expected to complete her thesis this June. Mr. Russel Peppers has started a doctoral thesis concerned with the spore and pollen populations from different types of sediments of Pennsylvanian age of Illinois.

Dr. Robert M. Kosanke is working on the palynology of Upper Mississippian and Lower Pennsylvanian coals. He hopes this can go to press before the end of the year. Dr. Robert H. Tschudy, Palynological Research Laboratory, Jamestown, Colorado, and Dr. Kosanke are currently working together on the description of Lower Permian spores and pollen grains from Texas.

University of Illinois

Dr. Harold W. Scott reports that the Department of Geology has recently hired Dr. William Hay, for service with the senior staff. Hay will teach Paleontology and direct research work the field of megascopic invertebrates. His personal interests are the Foraminifera and Ostracoda. He has prepared a major paper on the Tertiary Ostracoda of Europe, especially from France, Austria and Switzerland.

Dr. Scott's studies on ostracodes and foraminifera of Pakistan (Eocene) are still in progress. He anticipates that the ostracode paper will be ready by this summer and that on the foraminifera next year.

Investigations are under way on the development of the duplicature in Paleozoic ostracodes. At present, members of the Thlipsuridae and Healdiidae are being sectioned (without success). Dr. Scott says, "We expect to examine Ordovician specimens which have been assigned to the Podocopida. Some of the Ordovician *Macrocypris*? have been examined, but no duplicature-like structure could be observed."

Mr. Albert Guber is starting a Ph. D. thesis project on Cincinnatian ostracodes. He has completed part of his collecting work and the Indiana Geological Survey has kindly supplied him with some excellent material. This project is just getting under way.

Notre Dame University

From Dr. R. C. Gutschick we learn that micropaleontological efforts

have been concentrated on the study of Lower Mississippian microfaunas. This involves a study (near completion) of arenaceous foraminifera in the Welden limestone of Oklahoma, the Chappel limestone of central Texas and the Lodgepole limestone of southwestern Montana. Another study is under way on the microfaunas of the Lodgepole limestone in southwestern Montana. Dr. Gutschick is also working with Dr. Perry of Indiana University on the arenaceous foraminifera of the Sappington formation of southwestern Montana.

Dr. Erhard M. Winkler states that late- and post-Pleistocene freshwater ostracodes are under study, the one of Two Creeks age from a gravel pit near Ft. Wayne, Indiana, and the other of late Algonquin age from Bear Cave (Buchanan), Michigan. Further ostracode studies of similar age from other localities are planned.

Ohio State University

Most current work in micropaleontology in the Geology Department has to do with conodonts, and is being carried on by Dr. Walter C. Sweet and a number of his students. In June, he and Richard R. Pulse completed a study on the stratigraphic distribution and morphological variation of conodonts in the typical Fairview and McMillan formations, which serve as the reference standard for the North American Maysville stage. The results are scheduled for publication in the March number of the Journal of Paleontology.

At the present time, James Carpenter, a National Science Foundation Undergraduate Research Fellow, is making a carefully detailed study of the range and variations in conodonts from the type section of the Maysville, a section that is anomalous in many respects. Very recently, he was lucky enough to locate the bed in which the lowest Maysville fauna appears, thus demonstrating that a considerable part of this section is Eden in age.

Dr. Sweet writes, "With many interruptions by other matters, I am working on a magnificent collection of conodonts from the Pratt Ferry formation of Alabama. This association is distinctly Anglo-Scandinavian in aspect and has little in it to suggest presumably contemporaneous North American midcontinent forms that must have lived just a few miles away. Furthermore, it is, I believe, the first major fauna to be isolated from rocks in the Appalachian province.

"I hesitate to predict what we will be doing next year (or even in the next fortnight), but we hope to have a young Swedish micropaleontologist here working on Middle Ordovician conodonts of Kentucky, and we also hope to extend our studies of Ordovician conodonts to the type Trenton in New York and in Ontario next fall."

University of Michigan

Much time has been spent on the Ostracoda volume of the Treatise. A paper by R. V. Kesling, Emadeddin Kavary, Robert S. Takagi, John R. Tillman, and George R. Wulf on "Quasillitid and alanellid ostracods from the Centerfield limestone of western New York" appeared in the Contributions from the Museum of Paleontology, vol. 15, no. 2, pp. 15–31, 4 pls.

R. V. Kesling and Robert S. Takagi have a paper in press on a technique for weighing ostracodes using the Cartesian diver balance developed by Zeuthen. They studied a new species of Devonian *Welleria*. At present R. V. Kesling and Frederick S. Crafts are devising a refinement of the quartz-fiber torsion balance to weigh living ostracodes. Kesling and Richard Ploch have a paper nearly completed on an Upper Devonian *Cypridina*. Frederick S. Crafts, David G. Darby, Kenneth A. Shubak, and Raymond N. Smith, students in the advanced micropaleontology class, are studying the Black River ostracodes of Michigan. This fauna is very similar to that of the Middle Ordovician of Scandinavia, and yields the first occurrence of several genera in North America.

ROBERT V. KESLING
University of Michigan
Ann Arbor, Michigan

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Comments and Errata

Burma, B. H.

On the status of Theocampe Haeckel, and certain similar genera. Micropaleontology, vol. 5, no. 3, pp. 325–330, July, 1959.

On page 328, column 1, line 11: For "Dictyocephalus", read "Dictyocephala".

Green, K. E.

Ecology of some Arctic foraminifera. Micropaleontology, vol. 6, no. 1, pp. 57–78, pl. 1, text-figs. 1–9, January, 1960.

After this article had gone to press, the Editors learned that it had previously appeared in Volume 1 of *Scientific studies at Fletcher's Ice Island, T–3, 1952–1955* (Geophysical Research Papers, no. 63). The date of issue of this publication is given as September, 1959. Because of its availability, all conditions required for publication were fulfilled. Consequently, the six species designated as new in *Micropaleontology* should be suppressed and considered as new in no. 63 of the Geophysical Research Papers.

Lindström, M.

Conodonts from the Crug limestone (Ordovician, Wales). Micropaleontology, vol. 5, no. 4, pp. 427–452, pls. 1–4, text-figs. 1–3, October, 1959.

The genus name *Ctenognathus* Pander, 1856, is used for the synonym *Spathognathodus* Branson and Mehl, 1941. *Ctenognathus* Pander, 1856, is a junior homonym of *Ctenognathus* Fairmaire, 1843, and is thus invalid. *Spathognathodus* Branson and Mehl, 1941, is valid instead. The statements about *Ctenognathus* in Lindström's paper are no longer applicable. Professor W. C. Sweet has withdrawn his opinion regarding *Periodon* and *Phragmodus* which is quoted in support of Lindström's ideas on page 432 in the paper.

BROOKS F. ELLIS • ANGELINA R. MESSINA

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